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DYNAMIC TEAR TESTING OF FRONIUS-TIME AND LAGMAW WELDS

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DYNAMIC TEAR TESTING OF FRONIUS-TIME AND LAGMAW WELDS

by
K. MacKay - M.W. Chernuka

MARTEC LIMITED
1888 Brunswick Street, Suite 400
Halifax, Nova Scotia, Canada
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CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

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ABSTRACT

Dynamic tear specimens of welds from two previous DREA investigations were tested. The 25 mm thick specimens included two gas metal arc welds (Fronius-TIME) each made in HY80 and HY100 steels. A weld produced by laser assisted gas metal arc welding (LAGMAW) in HY80 steel was also tested with specimens notched in the weld metal and in the heat affected zone HAZ).

The HY80 Fronius-TIME 3G weld outperformed the HY80 Fronius-TIME lG/4G weld in the dynamic tear tests with the LAGMAW weld giving the poorest performance of the HY80 welds tested. For the HY100 the Froniuss-TIME lG/4G weld gave higher dynamic tear energies than the Fronius-TIME 3G weld. The LAGMAW HAZ specimens gave some of the highest dynamic tear energies for each test temperature which is possibly due to the fracture path including a combination of HAZ, weld metal, and parent metal. All welds tested met the requirement of 690 J at -29 °C except for the LAGMAW weld which gave a dynamic tear energy of 512 J at -5 °C.

RÉSUMÉ

Des éprouvettes de déchirement dynamique de soudures provenant de deux études précédentes du CRDA ont été testées. Les éprouvettes de 25 mm d'épaisseur comprenaient chacune deux soudures produites par le procédé à l'arc sous protection gazeuse avec fil électrode fusible (Fronius-TIME), chacune étant réalisée dans des aciers HY80 et HY100. Une soudure réalisée par le procédé de soudage à l'arc sous protection gazeuse avec fil électrode fusible assisté par laser (LAGMAW) dans de l'acier HY80 a aussi été testée sur des éprouvettes entaillées dans le métal foundu et dans la zone de transformation.

La soudure Frontius-TIME 3G réalisée dans l'acier HY80 a surclassé la soudure Fronius-TIME lG/4G réalisée dans l'acier HY80 au cours des essais de déchirement dynamique, et la soudure réalisée par le procédé LAGMAW a donné les moins bons résultats de tous les aciers HY80 testés. Dans le cas de l'acier HY100, la soudure Fronius-TIME lG/4G a donné des énergies de déchirement dynamique plus élevées que la soudure Fronius-TIME 3G. Les éprouvettes de zones de transformation de soudures réalisées par le procédé LAGMAW ont donné certaines des énergies de déchirement dynamique les plus élevées pour chaque température d'essai, ce qui est probablement dû au trajet de rupture s'étendant sur la zone de transformation, le métal fondu et le métal de base. Toutes les soudures testées respectaient l'exigence de 690 J à -29 °C, sauf la soudure réalisée par le procédé LAGMAW, qui a donné une énergie de déchirement dynamique de 512 J à -15 °C.

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1. INTRODUCTION

The Metallic Materials group of DREA has sponsored investigations into the development of all position gas metal arc welding (GMAW) of submarine steels [1,2,3]. To this end, they have conducted dynamic tear and explosion bulge tests to evaluate welds deposited in HY80 and HY100 steels. DREA has also been investigating the use of laser assisted gas metal arc welding (LAGMAW) for welding submarine steels [3]. This report gives the results of a contract to perform dynamic tear tests on submarine steel welds deposited using a Fronius-TIME welding system and a LAGMAW system.

2. THEORY

The dynamic tear test measures the amount of energy to fracture a single edge notched beam loaded dynamically in three point bending. The DT energy is the total energy required to fracture dynamic tear specimens and is a measure of resistance to rapid progressive fracturing. DT energy is determined from the area under a load-displacement curve. The load-displacement data is obtained by analyzing the load-time trace collected during a dynamic tear test using a velocity-energy balance relationship of the form

$$\frac{1}{2}mV_{i+1}^2 = \frac{1}{2}mV_i^2 - E_s + E_p \tag{2.1}$$

where

V_i and V_{i+1} are the velocities at time i and i+1

E_s is the energy lost to the specimen

and

E_p is energy gained from the crosshead falling during the time i to i+1.

E_s is estimated from the area under the load-time curve between times i and i+1 multiplied by the average velocity during this time period. A detailed description of the impact testing system is given in [4].

The shear index describes the fracture morphology by indicating the extent of shear lip formation at the sides of a fracture surface, as sketched in Figure 2.1. A flat fracture surface without shear lips, typical of a brittle fracture, has a shear index of 0. A ductile fracture surface where the shear lips touch has a shear index of 1. The shear index, S_I, can be determined by measuring the distance between the shear lips on a fracture surface and using

$$S_I = \frac{B-d}{B} \tag{2.2}$$

where

d = the distance between the shear lips

and

B = specimen thickness

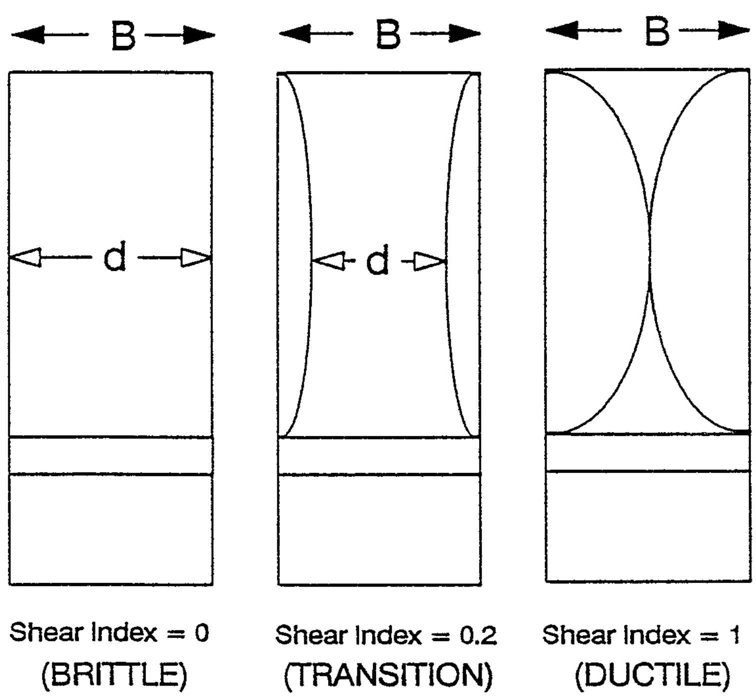


FIGURE 2.1: Typical Fracture Surfaces for Dynamic Tear Specimens
The shortest distance between the shear lips, d, is used
to calculate the shear index.

3. EXPERIMENTAL METHODS AND MATERIALS

The welds were deposited in 25 mm thick HY80 and HY100 plates. The chemical composition and mechanical properties of these steels are given in Tables 3.1 and 3.2, respectively. The Fronius-TIME welds in the HY80 steel were made using Lincoln LA100 wire and the HY100 welds were made using L-Tec 120 wire [2]. The LAGMAW welds in the HY80 steel also used LA100 wire. The chemical composition of these wires are also given in Table 3.1.

The HY80 welds consisted of 3G (vertical down) Fronius TIME welds, 1G/4G (flat/overhead) Fronius-TIME welds, and LAGMAW welds. The HY100 welds consisted of Fronius-TIME welds made in the 3G (vertical down) and in the 1G/4G (flat/overhead) positions. The Fronius-TIME welds were prepared by Weld Process International Limited [1] and the LAGMAW welds were prepared by The Laser Institute [3]. Summaries of the welding procedures are given in Table 3.3. Complete details of the Froninus-Time welding and LAGMAW welding procedures can be found in other reports [2, 3].

A sketch of the submarine weld specimens are shown in Figure 3.1. The notches in the Fronius-TIME specimens where located along the weld metal centerline. The LAGMAW weld specimens were notched at the weld metal centerline or in the heat affected zone (HAZ) of the weld. The machined notches were sharpened by pressing a tool steel blade 0.25 mm into the notch as outlined in ASTM standard E604 [5].

The specimens were tested in accordance with ASTM standard E604 [5]. The setup for the dynamic tear test is shown in Figure 3.2. The specimens were cooled for a minimum of 15 minutes at the desired temperature in a methanol bath and then placed on the anvil of the drop tower. The specimens were impacted by releasing the 275 kg crosshead from a preset height of 1.52 m above the specimen. The specimens were impacted within 10 seconds from the time they were removed from the bath to ensure that specimen temperature change was minimal. For each test, a force-time record was recorded using a Nicolet 204A digital oscilloscope to capture the signal from the Dynatup ETI 600 signal conditioner connected to the instrumented tup. The load-time data was transferred to a Tektronic 4054 computer which converted the data to load-displacement using a velocity-energy balance

relationship. The dynamic tear energy was calculated by numerically integrating the area under the load-displacement curve. The shear index was calculated based on the shortest distance between the shear lips on the fracture surfaces, as measured using vernier callipers.

TABLE 3.1: Chemical Compositions (wt%) of Steel Plates and Electrode Wires (from [1])

Material	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	Ti	Zr	As	Sb	Sn
HY80*	.145	.26	.008	.007	.19	.11	2.23	1.40	.34		.005	.002		.009	.014	.009
HY100	.140	.25	.007	.004	.20	.12	2.67	1.41	.34	.030	.002	.001		.007	.001	.010
Lincoln LA100 Wire	.07	1.47	.007	.007	.34	.11	1.81	.05	.34							
L-Tec 120 Wire	.06	1.63	.006	.005	.38	.01	2.37	.31	.50	.012	.001	.010	.015			

* HY80 plate used for LAGMAW welds had a slightly different chemical composition with 2.42% Ni, 1.49% Cr, and 0.41% Mo.

TABLE 3.2: Mechanical Properties of Steel Plates (from [1])		
Property	HY80*	HY100
Yield Strength (MPa)	638	724
UTS (MPa)	741	805
Hardness (BHN)	229	245

* determined from plate used for Fronius-TIME weldments.

TABLE 3.3: Summary of Welding Procedures

Specimen ID	Machine	Wire Diameter (mm)	Steel	Shielding Gas	Average Wire Speed (m/min)	Average Current (A)	Average Travel Speed (mm/sec)	Average Heat Input (kJ/mm)	Number of Passes
C*	Fronius	1.2	HY80	TIME	8.1	209	8.3	0.62	14
CC*	Fronius	1.2	HY100	TIME	8.9	234	8.1	0.85	12
D*	Fronius	1.2	HY80	TIME	7.0	188	6.6	0.71	13
DD*	Fronius	1.2	HY100	TIME	9.6	230	6.1	1.16	11
LASER**	CE 5000-Hobart	1.6	HY80	50% He 50% Ar	N/A	415	10.6	1.6	4

* from [2]
** from [3]

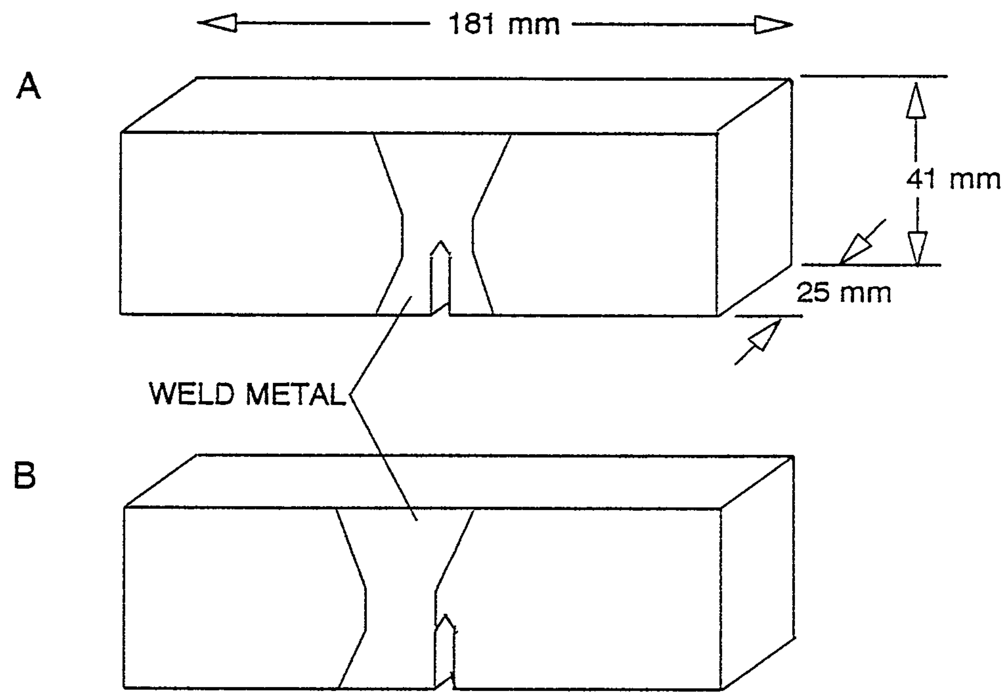


FIGURE 3.1: Sketch of the Dynamic Tear Weld Specimens
a) Notched at the weld metal centerline, and
b) Notched in the heat affected zone (HAZ)

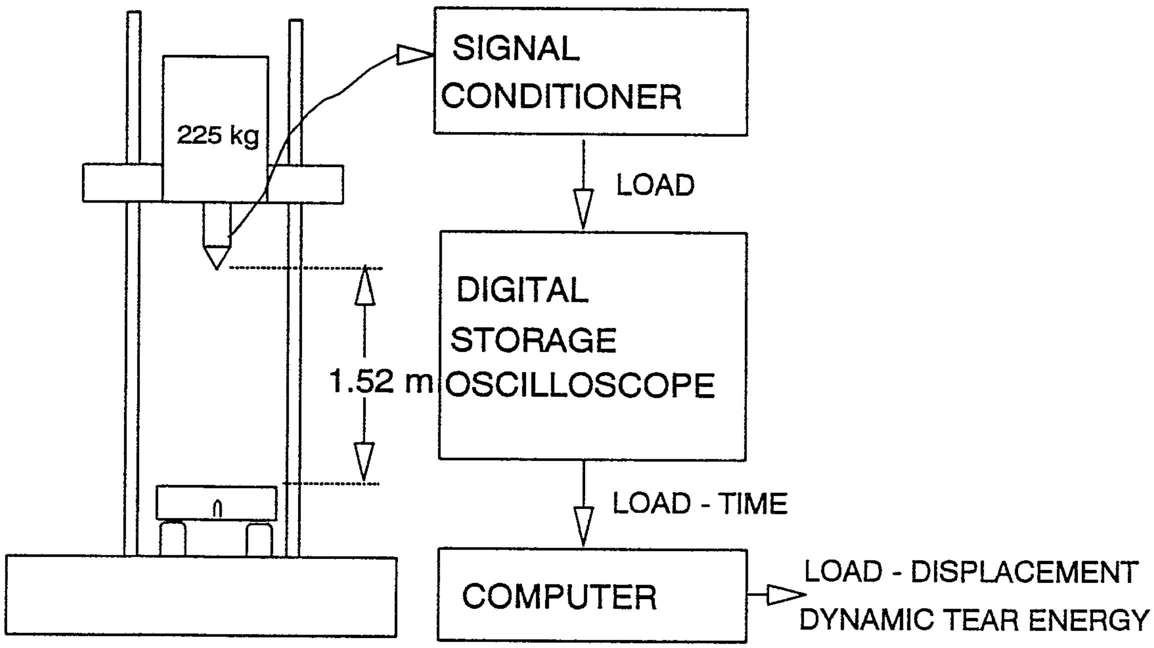


FIGURE 3.2: Dynamic Tear Test Setup

4. RESULTS AND DISCUSSION

Table 4.1 gives the dynamic tear test results for the welds. The load-displacement curves for each specimen can be found in Appendix A. Figure 4.1 shows the transition curves for each weld.

The LAGMAW weld metal specimens gave the poorest performance of the HY80 welds. The dynamic tear energy (DTE) ranged between 512 to 1256 J between -45°C and 0°C with an increase to 1958 J at 15°C. The transition curve for the LAGMAW weld metal is unusual with the lowest DTE of 512 J at -15°C and DTE's of 660 J and 1256 J at -45 and -30°C, respectively. The erratic behaviour of these specimens was due to weld defects and to differences in the fracture paths. The fracture path of the LAGMAW specimen tested at -30°C contained approximately 30% weld metal whereas the fracture path for the specimens tested at -45, -15, and 0°C included approximately 90% weld metal and 10% HAZ. The fracture path of the LAGMAW specimen tested at 15°C contained 20% weld metal, 10% HAZ and 70% parent material. Note that the estimation of the fracture path is only approximate due to the difficulties in defining the material (i.e. weld metal, HAZ and parent) along the fracture path in the centre of the specimen which can be complicated by the presence of large shear lips. The LAGMAW weld was the only weld to exhibit a DTE of less than 690 J above -30°C and therefore does not meet the specification of 690 J at -29°C (even though the DTE's at -45°C and -30°C were 660 J and 1256 J, respectively).

The LAGMAW HAZ specimens gave some of the highest DTEs for the HY80 welds. The transition curve shows the DTE decreasing from 1999 J at -45°C to 1547 J at -15°C before increasing to 1956 J and 2883 J at 0°C and 15°C, respectively. It is difficult to draw conclusions from these specimens as the fracture path included a combination of HAZ, weld metal, and parent material. Examination of the fractured specimens show that the fracture paths included between 10% and 30% HAZ. It can be said that fracture initiated in the LAGMAW HAZ, with this loading geometry, requires substantially more energy than fracture initiated along the LAGMAW weld centerline. (A similar increase in HAZ DTE from weld metal DTE was also reported by Malik [1] for various Fronius welds and a conventional TIME weld in HY80 steel.)

The transition curve for the HY80 Fronius-TIME 3G weld is shown in Figure 4.1. The curve shows a low of 1302 J at -30°C with a relatively sharp increase to the upper shelf with DTEs of 2269 J and 2214 J at 0°C and 15°C, respectively. The only irregular point on this curve is the 1773 J at -45°C which was greater than the 1302 J recorded at -30°C. The HY80 Fronius-TIME 3G weld gives higher DTEs than the HY80 Fronius-TIME 1G/4G weld over the test temperature range except at 15°C where the DTEs are comparable. The HY80 Fronius-TIME 1G/4G weld DTEs show a relatively gradual increase from 757 J at -45°C to 1506 J at 0°C and then there is a jump to 2502 J at 15°C.

The transition curves for the two HY100 welds are also shown in Figure 4.1. The slopes of these curves are low compared to the those of the HY80 welds, which is typical of high strength steels. The DTE of the HY100 Fronius-TIME 1G/4G weld increases almost linearly from 651 J at -45°C to 845 J at -15°C. The upper shelf is defined by the 1053 J and 1081 J DTEs at 0°C and 15°C, respectively. Only two HY100 Fronius-TIME 3G weld specimens were tested with both giving lower DTEs than the HY100 1G/4G welds. The 3G welds gave DTEs of 691 J at -30°C and 837 J at 0°C compared to 778 J and 1053 J for the 1G/4G welds.

Figure 4.2 plots shear index against temperature for all of the specimens tested. The shear index values for the LAGMAW specimens are lower than those of the other welds. The LAGMAW specimens show erratic shear index values which is consistent with the DTE curves. The HY80 welds show a general increase in shear index with temperature. The 1G/4G HY100 weld gives relatively uniform shear under values over the temperature range, while the 3G HY100 weld shows a decrease in shear index from -30 to 0°C.

TABLE 4.1: Dynamic Tear Test Results for Fronius-TIME and Laser Welds

Specimen	Plate	Weld	Velocity (m/s)	Temp. (°C)	DTE (J)	Shear Index
C2-5	HY80	3G FRONIUS TIME	5.47	-45	1773	0.481
C2-3	HY80	3G FRONIUS TIME	5.47	-30	1302	0.559
C2-4	HY80	3G FRONIUS TIME	5.47	-15	1676	0.573
C2-2	HY80	3G FRONIUS TIME	5.47	0	2269	0.615
C2-1	HY80	3G FRONIUS TIME	5.47	15	2214	0.651
CC3-2	HY100	3G FRONIUS TIME	5.47	-30	691	0.553
CC3-1	HY100	3G FRONIUS TIME	5.47	0	837	0.470
D4-5	HY80	1G/4G FRONIUS TIME	5.47	-45	757	0.464
D4-3	HY80	1G/4G FRONIUS TIME	5.47	-30	1247	0.542
D4-4	HY80	1G/4G FRONIUS TIME	5.47	-15	1434	0.534
D4-2	HY80	1G/4G FRONIUS TIME	5.47	0	1506	0.570
D4-1	HY80	1G/4G FRONIUS TIME	5.47	15	2502	0.772
DD4-5	HY100	1G/4G FRONIUS TIME	5.47	-45	651	0.472
DD4-3	HY100	1G/4G FRONIUS TIME	5.47	-30	778	0.524
DD4-4	HY100	1G/4G FRONIUS TIME	5.47	-15	845	0.516
DD4-2	HY100	1G/4G FRONIUS TIME	5.47	0	1053	0.517
DD4-1	HY100	1G/4G FRONIUS TIME	5.47	15	1081	0.509
LASER3	HY80	LASER WELD METAL	5.47	-45	660	0.198
LASER1	HY80	LASER WELD METAL	5.47	-30	1256	0.396
LASER5	HY80	LASER WELD METAL	5.47	-15	512	0.224
LASER7	HY80	LASER WELD METAL	5.47	0	963	0.374
LASER9	HY80	LASER WELD METAL	5.47	15	1958	0.441
LASER4	HY80	LASER HAZ	5.47	-45	1999	0.439
LASER2	HY80	LASER HAZ	5.47	-30	1800	0.432
LASER6	HY80	LASER HAZ	5.47	-15	1547	0.364
LASER8	HY80	LASER HAZ	5.47	0	1956	0.478
LASER10	HY80	LASER HAZ	5.47	15	2883	0.509

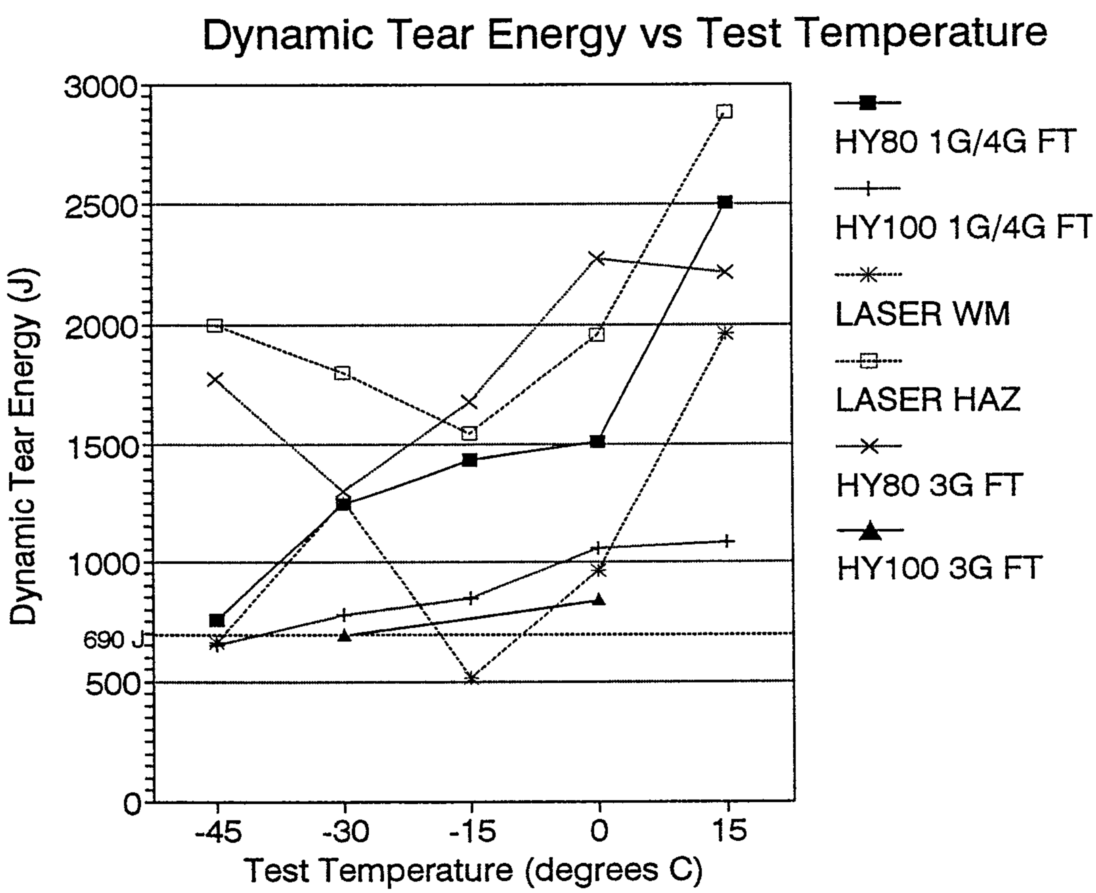


FIGURE 4.1: Transition Curves for Welds Deposited in HY80 and HY100 Steel

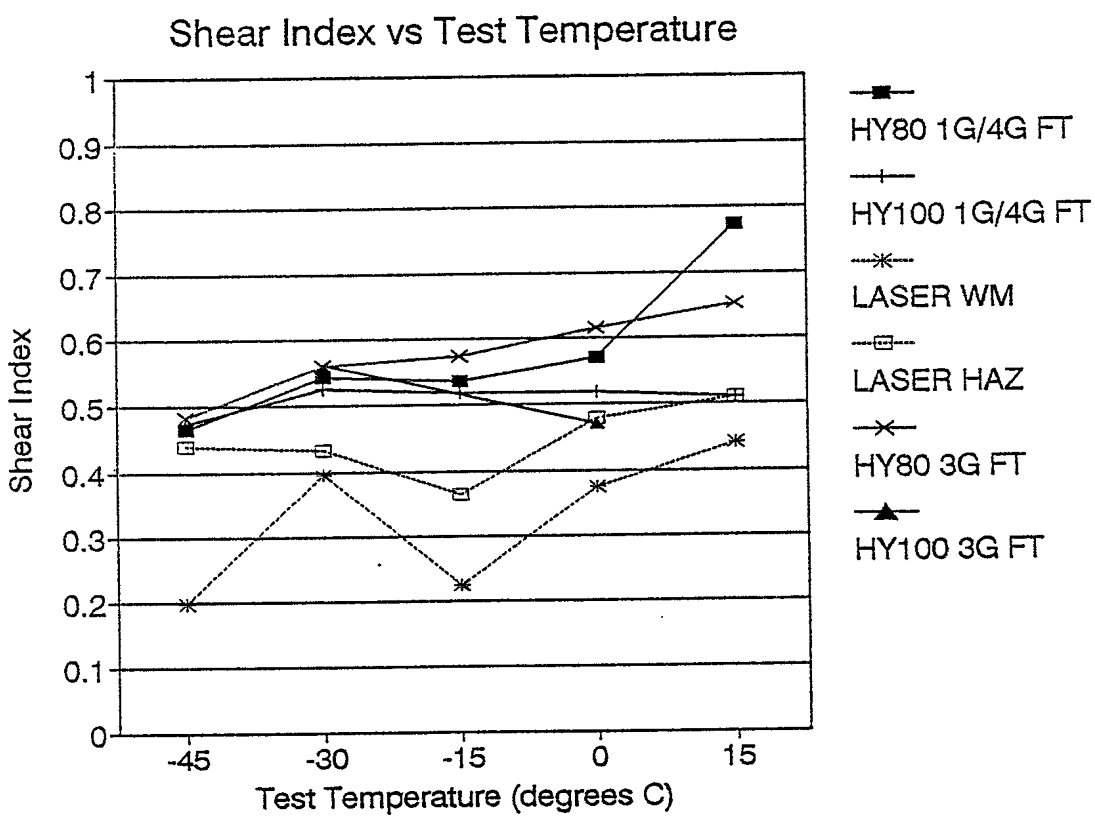


FIGURE 4.2: Shear index plotted against test temperature.

5. CONCLUSIONS

All welds tested met the requirement of 690 J at -29°C except for the LAGMAW weld which gave a dynamic tear energy of 512 J at -15°C.

The HY80 Fronius-TIME 3G weld outperformed the HY80 Fronius-TIME 1G/4G weld at test temperatures ranging from -45°C to 0°C. For the HY100 welds the reverse was found with the Fronius-TIME 1G/4G weld giving higher dynamic tear energies than the Fronius-TIME 3G weld. The LAGMAW weld gave the poorest performance of the HY80 welds.

The LAGMAW HAZ specimens gave some of the highest dynamic tear energies for each test temperature which is possibly due to the fracture path including a combination of HAZ, weld metal, and parent metal.

REFERENCES

1. L. Malik, "**Further Mechanical Testing of Welds Made in Two Previous DREA Welding Programs**", DREA Contract Report CR/93/419, April, 1993.

2. L. Malik, K.G. Morrison, and L.N. Pussegoda, "**All Position Gas Metal Arc Welding of HY80 and HY100 Steels**", DREA Contract Report CR/91/434, May, 1991.

3. K.H. Maggee, "**An Experimental Study of Laser Assisted Arc Welding**", DREA Contract Report CR/93/430, March, 1993.

4. K.J. Allen, K.J. Rhyno, and J.R. Matthews, "**Calibration of the DREA Instrumented Impact Testing System**", DREA Note No. DL/85/1, January, 1985, Informal Report.

5. "**E604 Standard Test Method Dynamic Tear Testing of Metallic Materials**", 1994 Annual Book of ASTM Standards, Vol. 03.01, American Society for Testing and Materials, 1994, pp. 514-521.

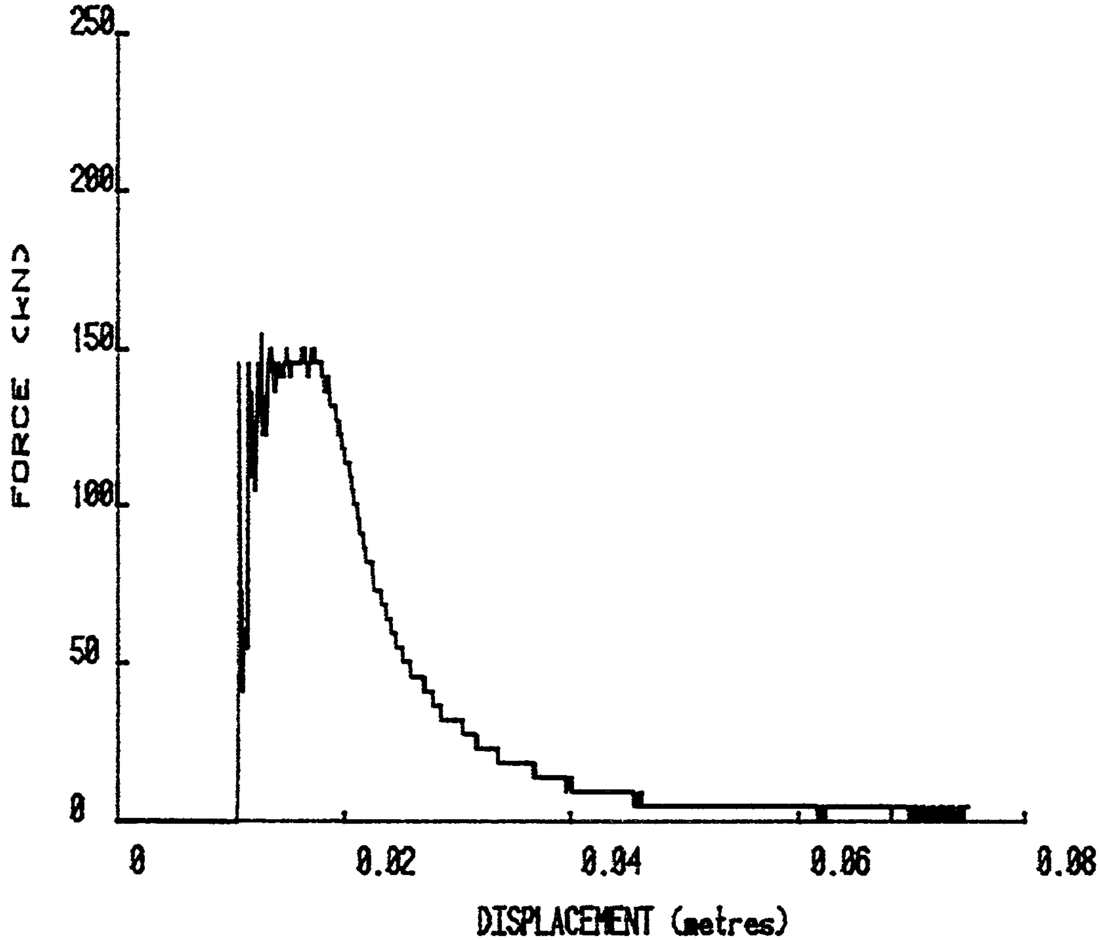
APPENDIX A:

LOAD-DISPLACEMENT CURVES

LOAD/LPD PLOT FOR: C2-1 HY80 3GFRONIUS TIME 15C 16/1/3

DYNAMIC TEAR ENERGY	2213.9 joules
	1633 ftlbs
Shear Index	0.651

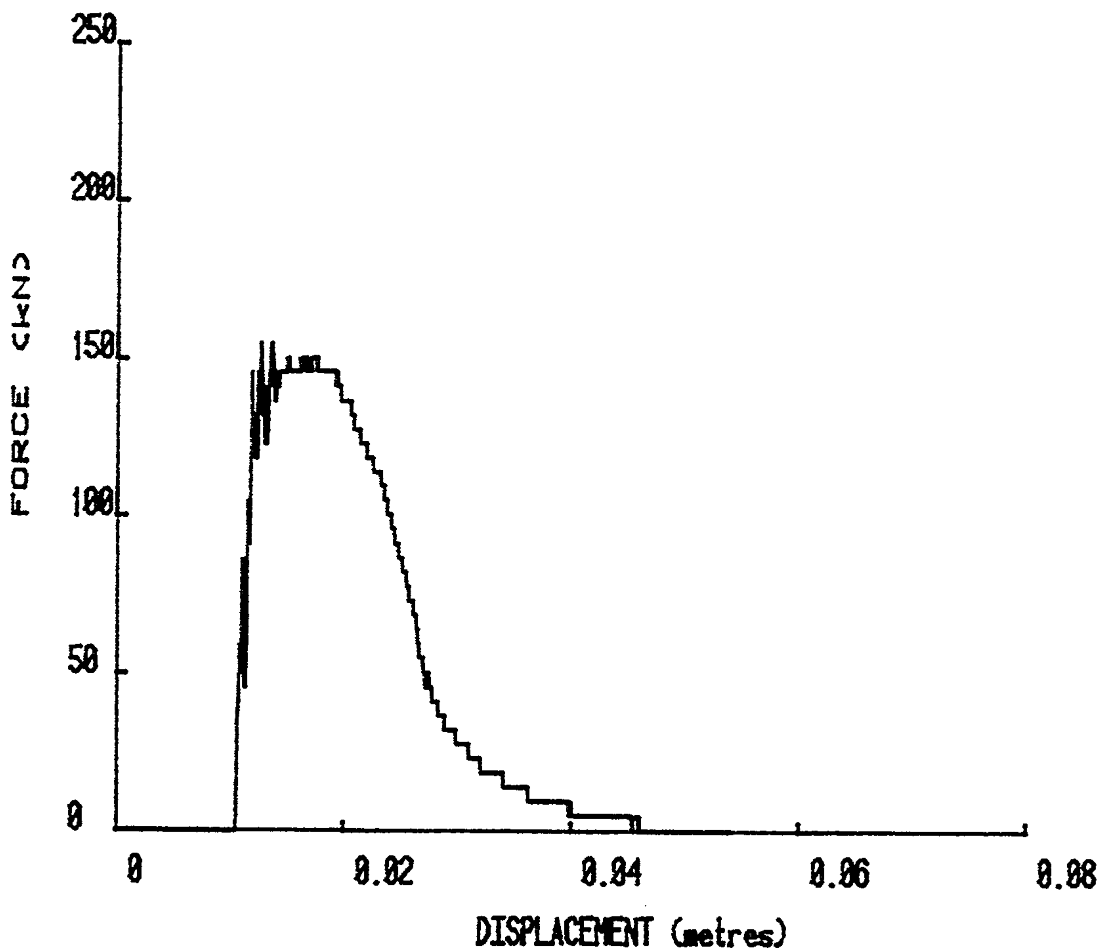
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: C2-2 HY80 3GFRONIUS TIME 0C 15/8/6

DYNAMIC TEAR ENERGY	2269.4 joules 1674 ftlbs
Shear Index	0.615

Impact Velocity = 5.47 m/s
17.9 ft/sec

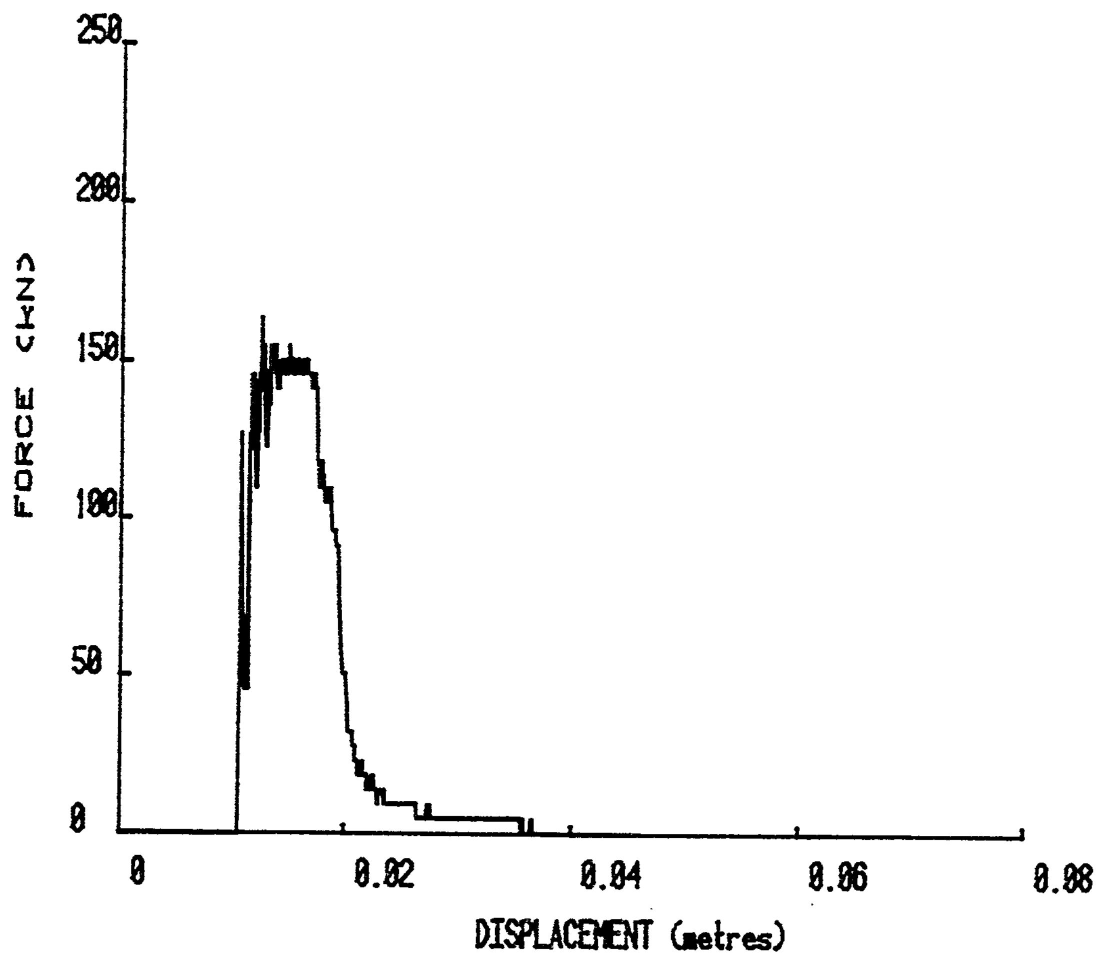


LOAD/LPD PLOT FOR: C2-3 HY80 3GFRONIUS TIME -30C 15/6/5

DYNAMIC TEAR ENERGY 1302.4 joules
962 ftlbs

Shear Index 0.559

Impact Velocity = 5.47 m/s
17.9 ft/sec

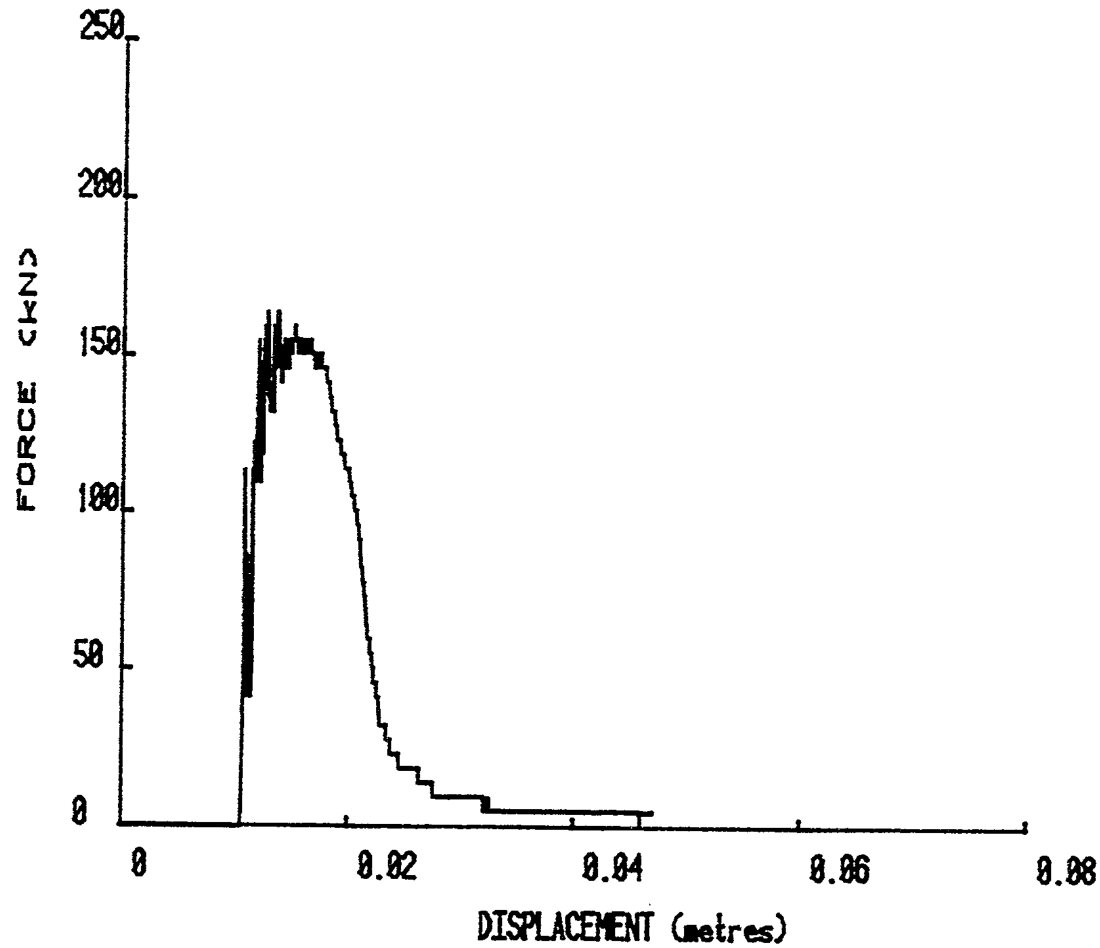


LOAD/LPD PLOT FOR: C2-4 HY80 3GFRONIUS TIME -15C 15/7/7

DYNAMIC TEAR ENERGY 1676.3 joules
1237 ftlbs

Shear Index 0.573

Impact Velocity = 5.47 m/s
17.9 ft/sec

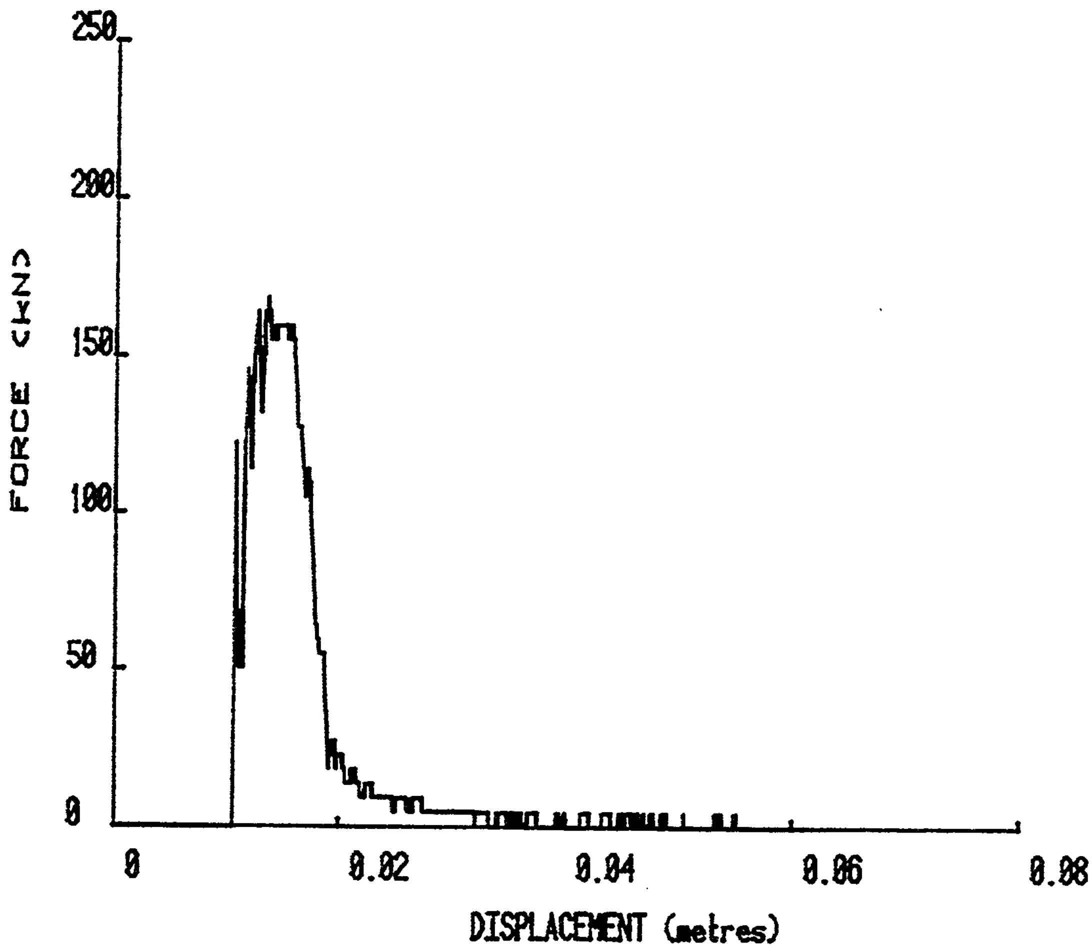


LOAD/LPD PLOT FOR: C2-5 HY80 3GFRONIUS TIME -45C 15/7/1

DYNAMIC TEAR ENERGY 1172.9 joules
865 ftlbs

Shear Index 0.481

Impact Velocity = 5.47 m/s
17.9 ft/sec

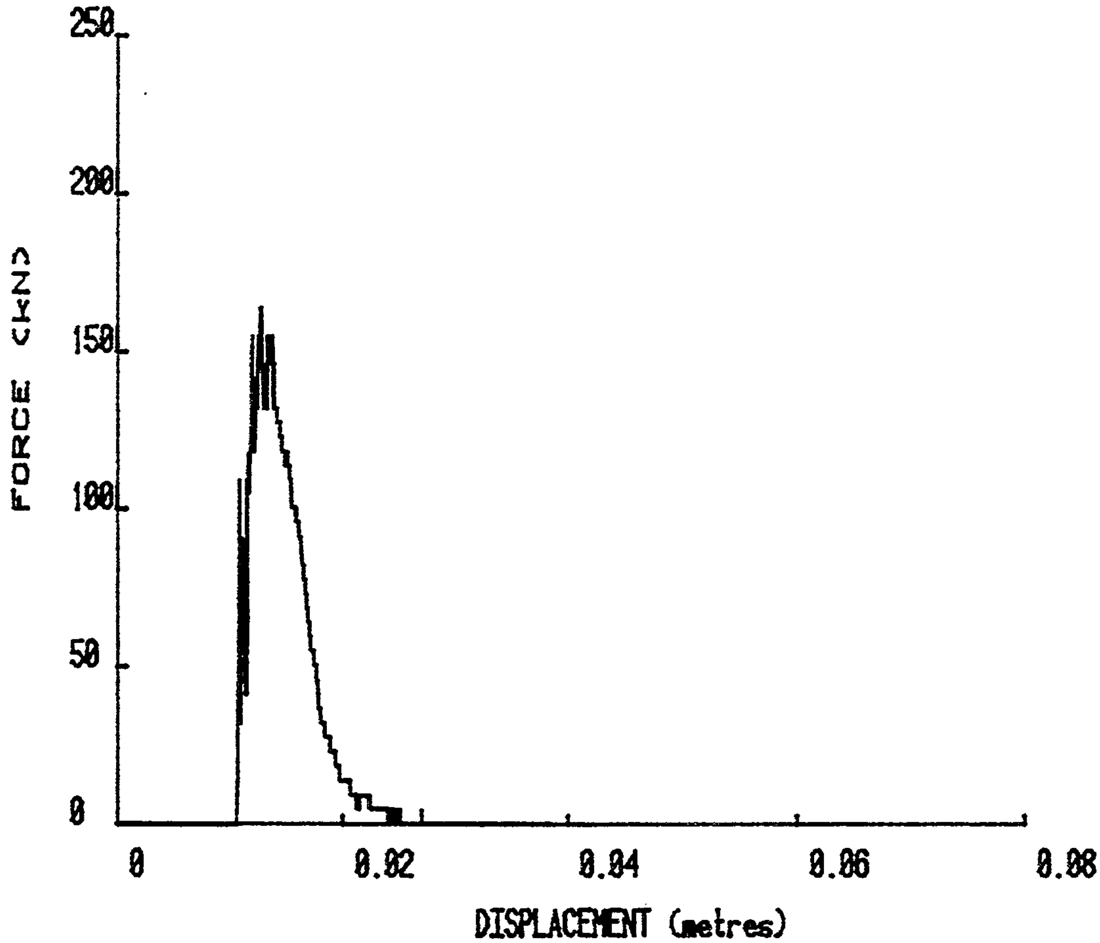


LOAD/LPD PLOT FOR: CC3-1 HY100 3GFRONIUS TIME 0C 15/8/5

DYNAMIC TEAR ENERGY 837.2 joules
618 ftlbs

Shear Index 0.47

Impact Velocity = 5.47 m/s
17.9 ft/sec

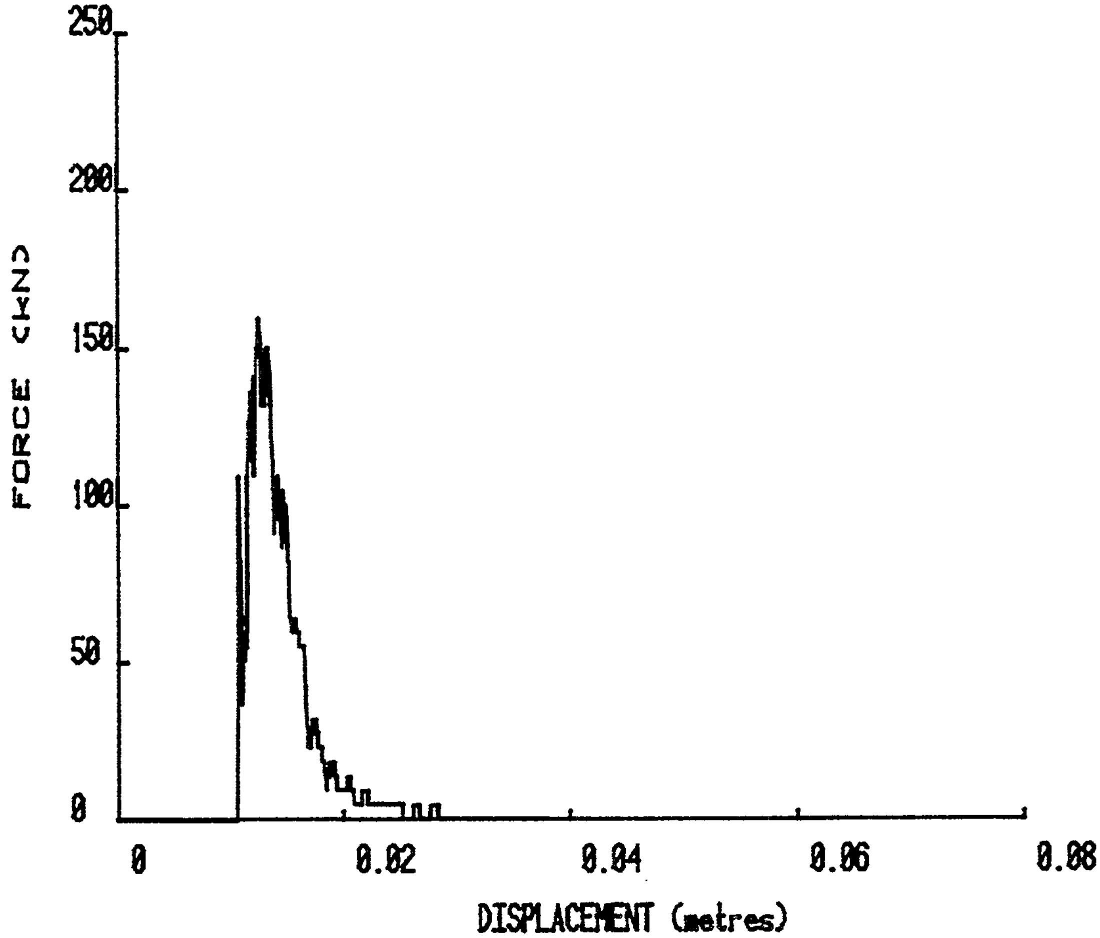


LOAD/LPD PLOT FOR: CC3-2HY1003GFRONIUS TIME-30CT15/6/2

DYNAMIC TEAR ENERGY 690.8 joules
510 ftlbs

Shear Index 0.552

Impact Velocity = 5.47 m/s
17.9 ft/sec

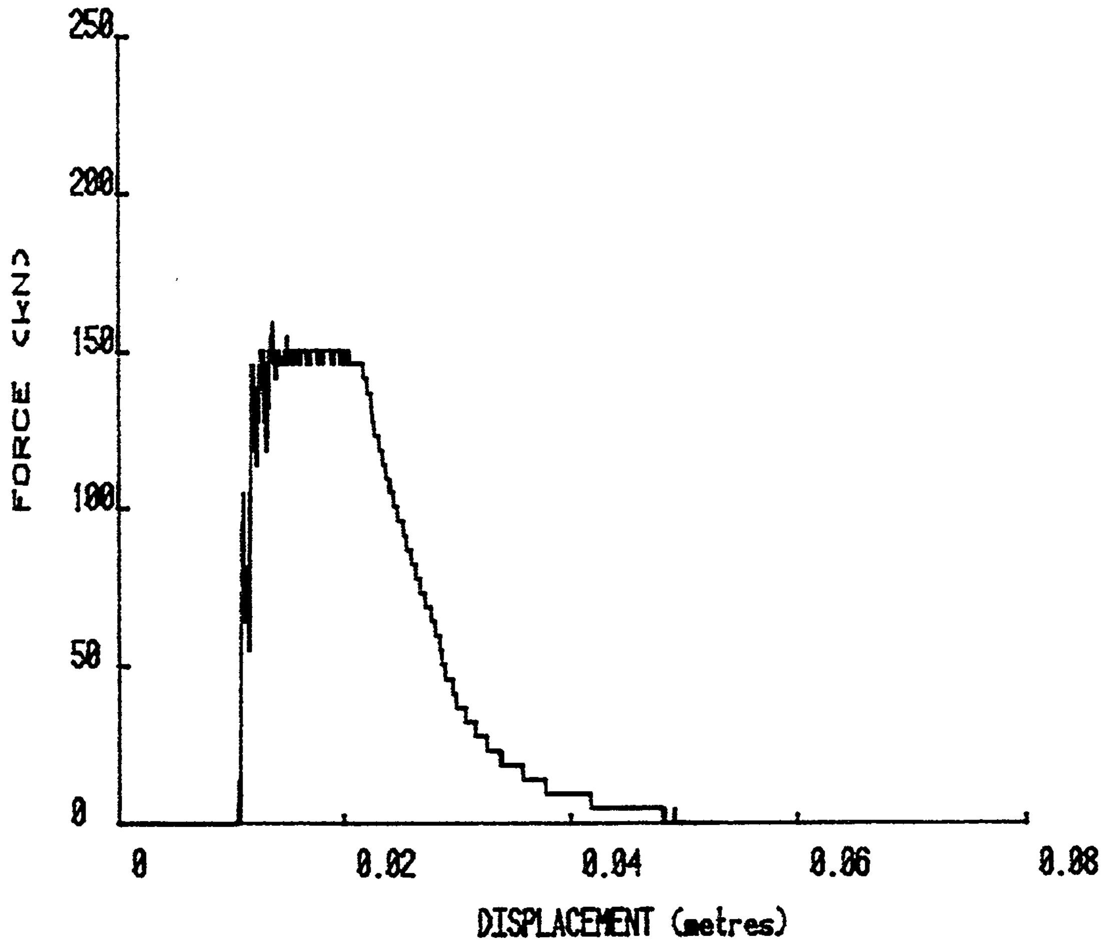


LOAD/LPD PLOT FOR: D4-1 HY80 1646FRONIUS TIME 15C 16/1/4

DYNAMIC TEAR ENERGY 2502.3 joules
1846 ftlbs

Shear Index 0.772

Impact Velocity = 5.47 m/s
17.9 ft/sec

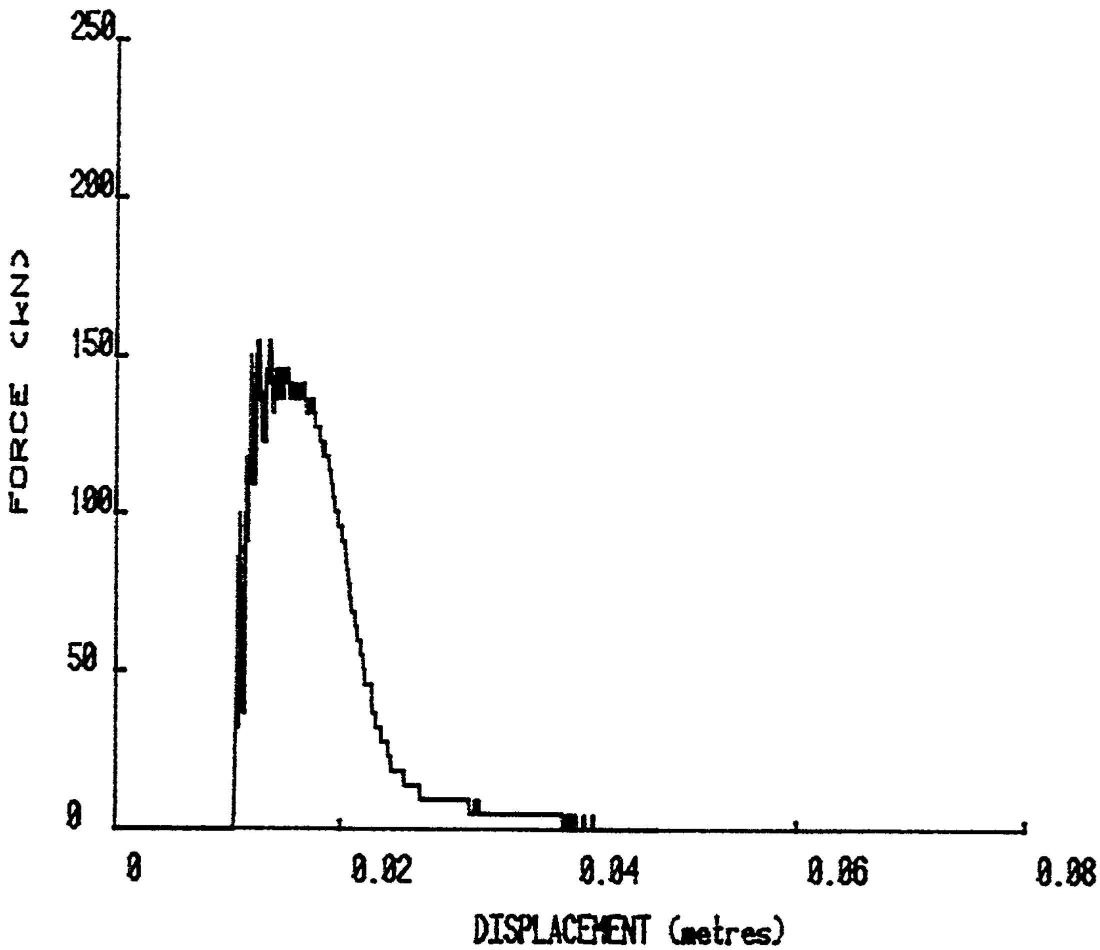


LOAD/LPD PLOT FOR: D4-2 HY80 1G4GFRONIUS TIME 0C 15/8/7

DYNAMIC TEAR ENERGY 1506.3 joules
1111 ftlbs

Shear Index 0.57

Impact Velocity = 5.47 m/s
17.9 ft/sec

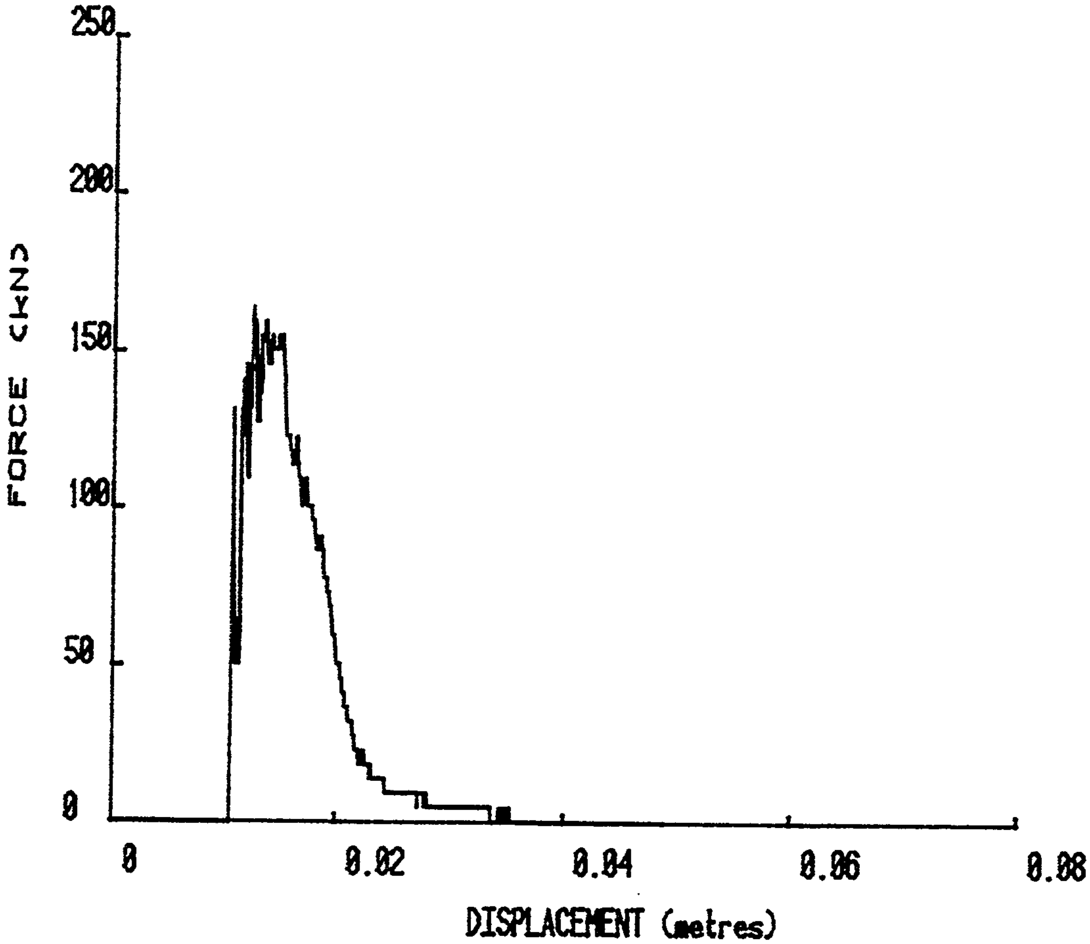


LOAD/LPD PLOT FOR: D4-3 HY80 164G FRONIUS TIME -30C 16/6/6

DYNAMIC TEAR ENERGY 1246.6 joules
919 ftlbs

Shear Index 0.542

Impact Velocity = 5.47 m/s
17.9 ft/sec

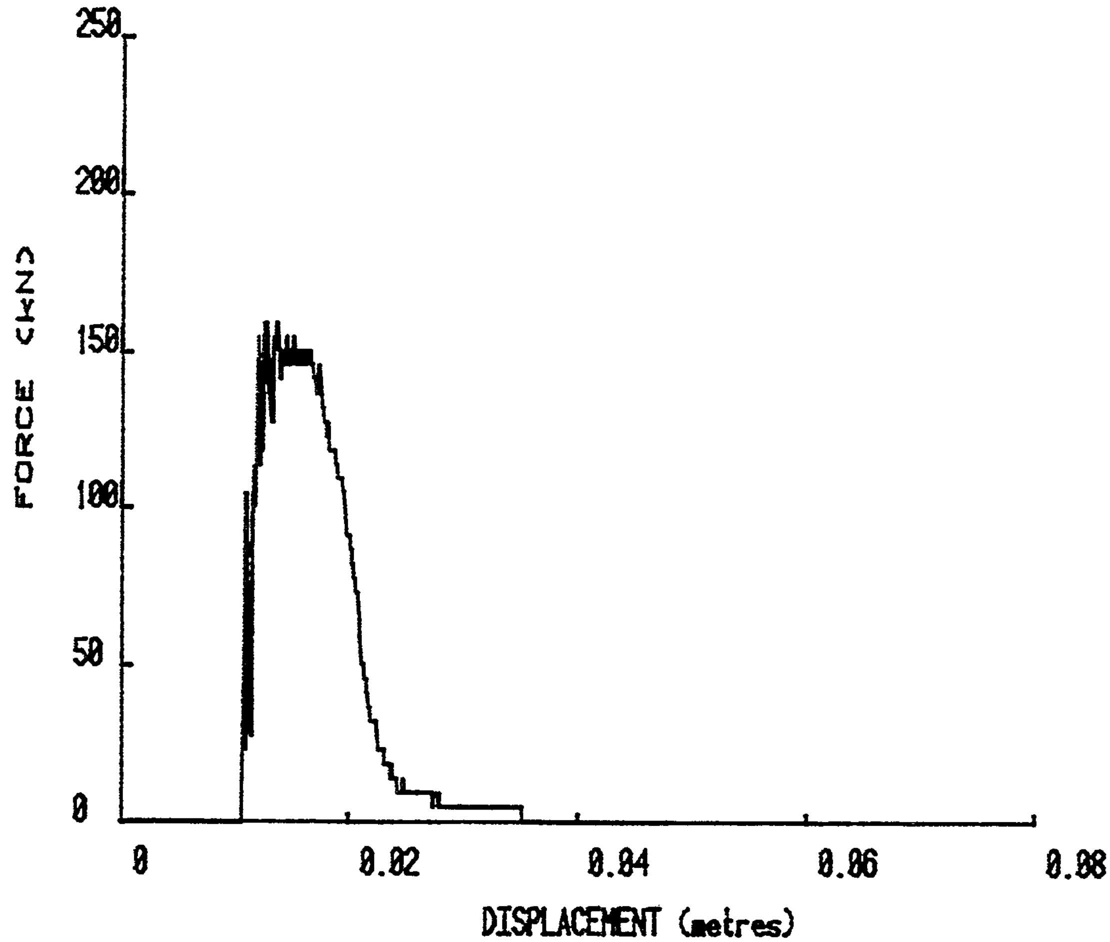


LOAD/LPD PLOT FOR: D4-4 HY80 164GFRONIUS TIME -15C 15/8/1

DYNAMIC TEAR ENERGY 1434.3 joules
1058 ftlbs

Shear Index 0.534

Impact Velocity = 5.47 m/s
17.9 ft/sec

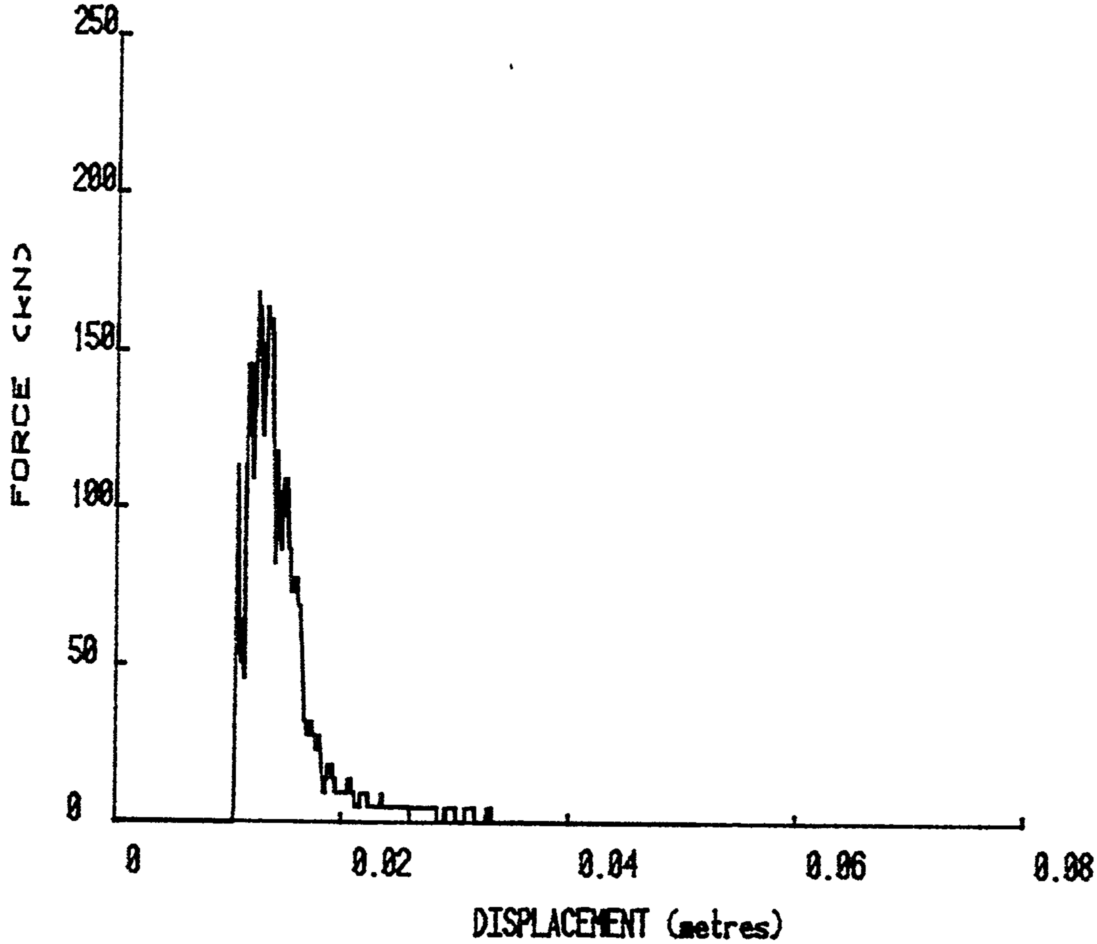


LOAD/LPD PLOT FOR: D4-5 HY80 164GFRONIUS TIME -45 15/7/4

DYNAMIC TEAR ENERGY 765.6 joules
565 ftlbs

Shear Index 0.464

Impact Velocity = 5.47 m/s
17.9 ft/sec

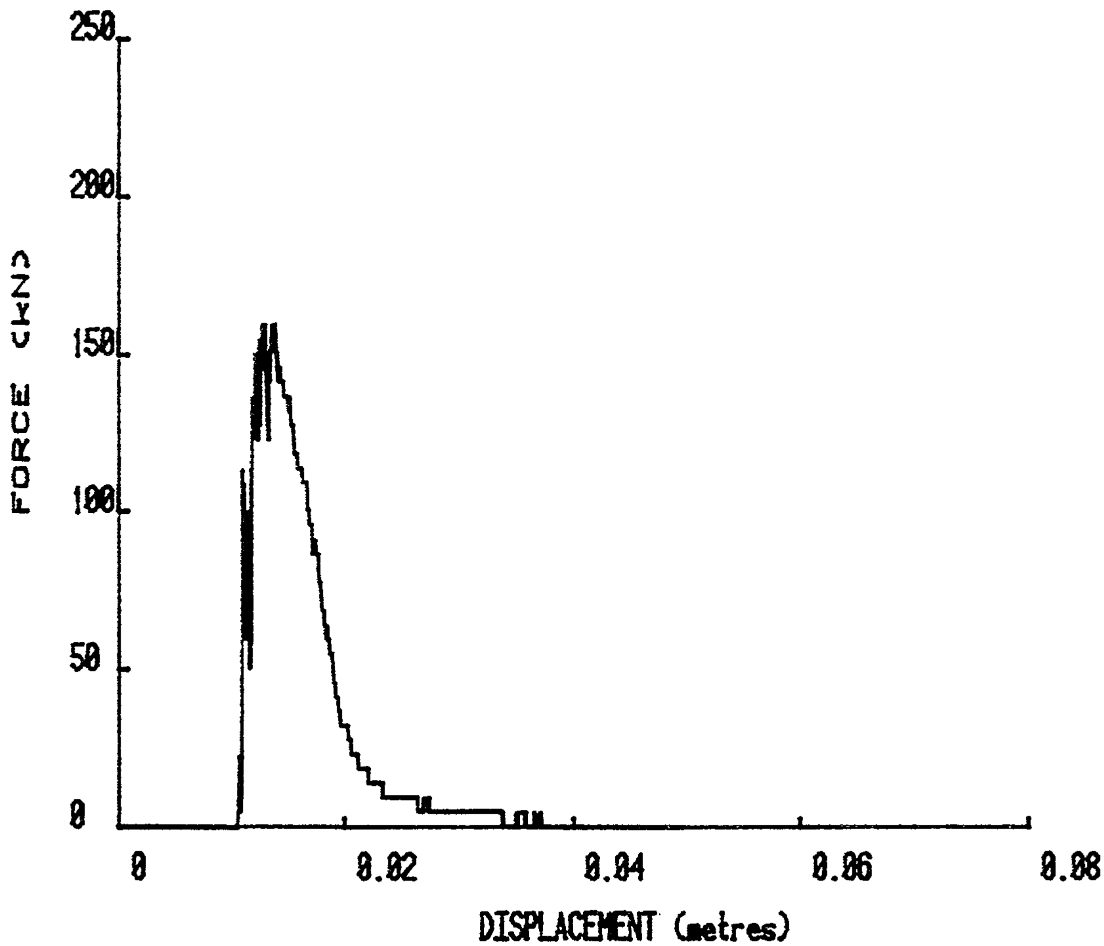


LOAD/LPD PLOT FOR: DD4-1 HY100 164GFRONIUS TIME 15C 16/1/5

DYNAMIC TEAR ENERGY 1081.3 joules
798 ftlbs

Shear Index 0.509

Impact Velocity = 5.47 m/s
17.9 ft/sec

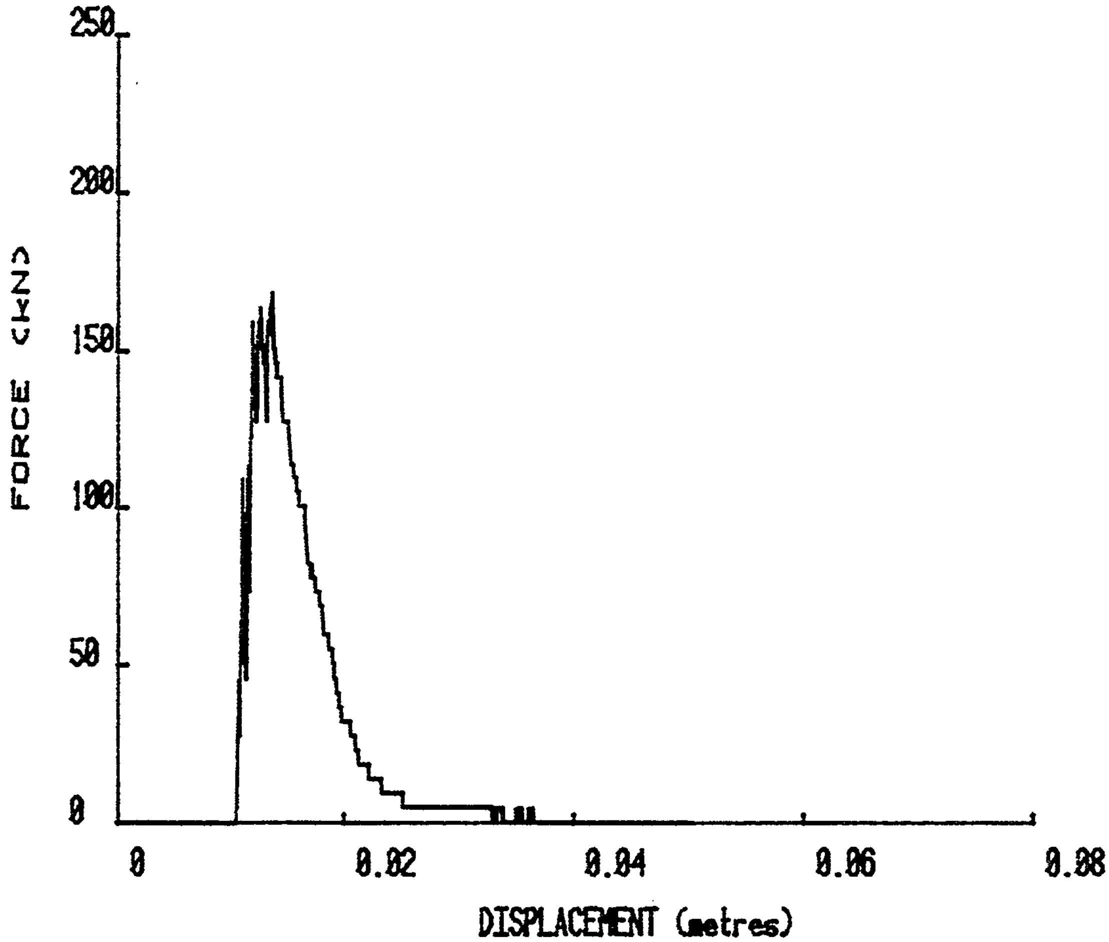


LOAD/LPD PLOT FOR: DD4-2 HY100 164GFRONIUS TIME 0C 15/8/8

DYNAMIC TEAR ENERGY 1053.1 joules
777 ftlbs

Shear Index 0.517

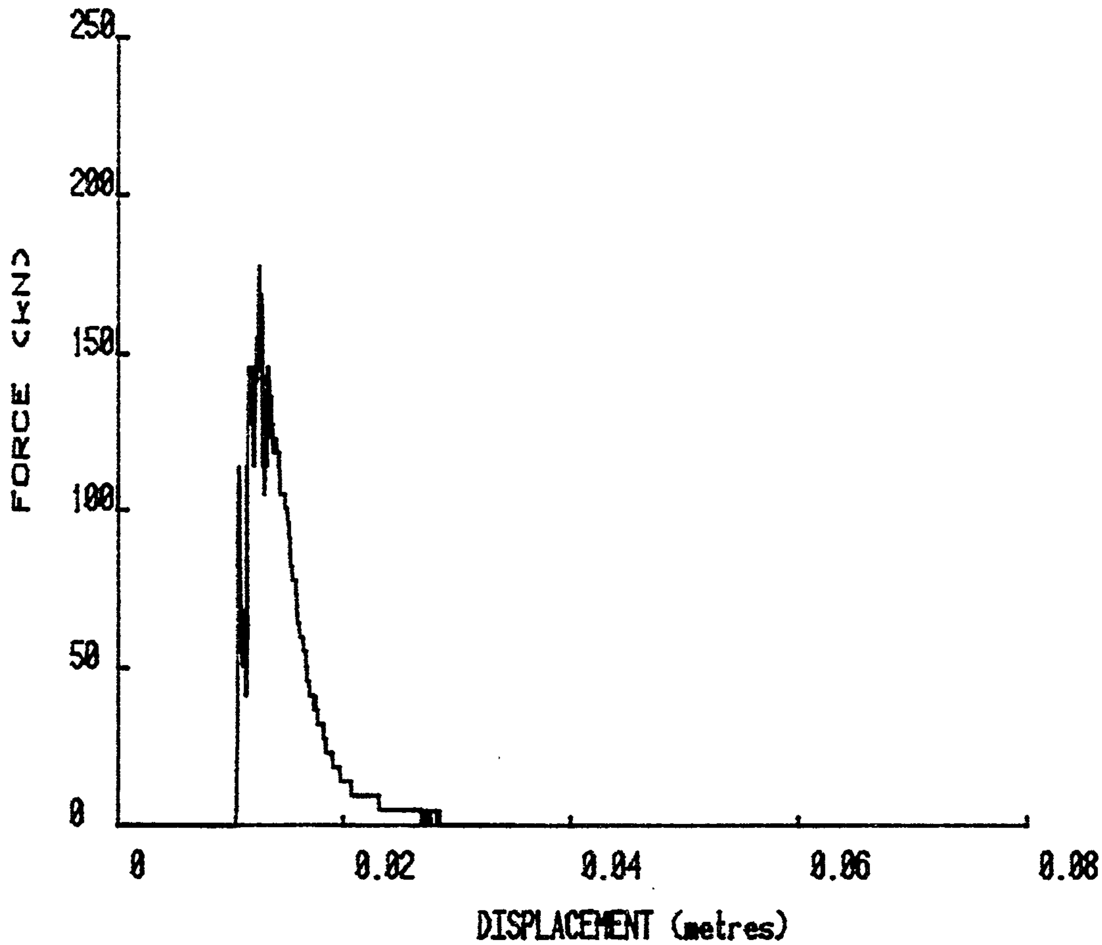
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: DD4-3 HY100 1G4GFRONIUS TIME -30C 15/6/7

DYNAMIC TEAR ENERGY	777.8 joules
	574 ftlbs
Shear Index	0.524

Impact Velocity = 5.47 m/s
17.9 ft/sec

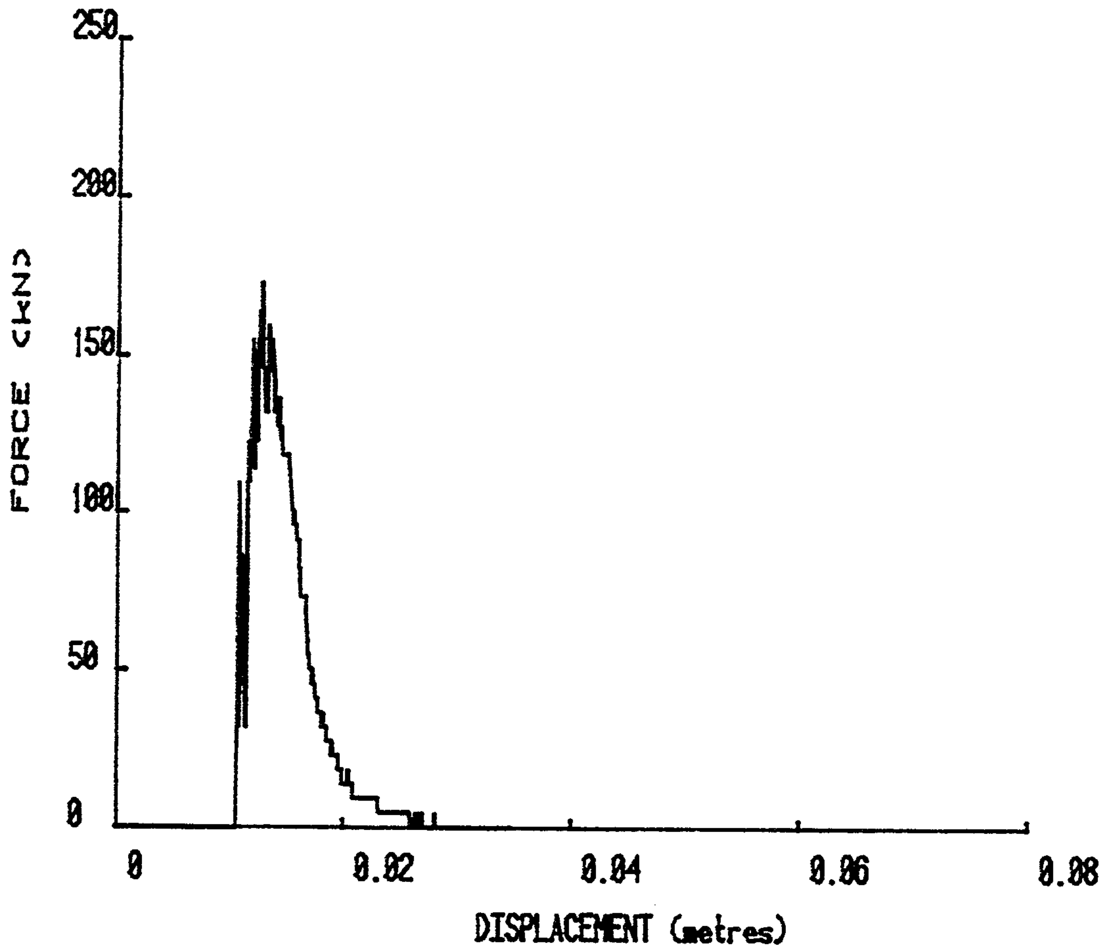


LOAD/LPD PLOT FOR: DD4-4 HY100 164GFRONIUS TIME -15C 15/8/2

DYNAMIC TEAR ENERGY 844.7 joules
623 ftlbs

Shear Index 0.516

Impact Velocity = 5.47 m/s
17.9 ft/sec

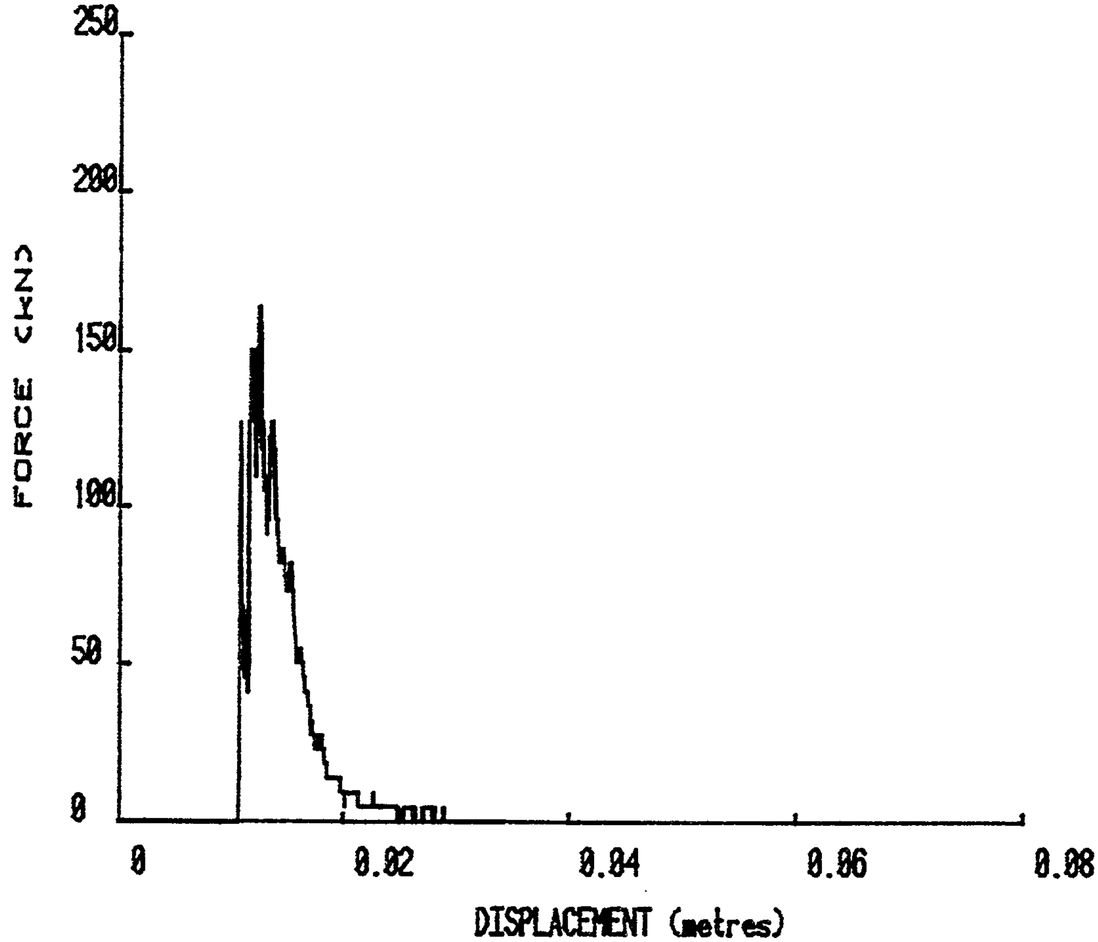


LOAD/LPD PLOT FOR: DD4-5 HY100 164GFRONIUS TIME -45C115/7/5

DYNAMIC TEAR ENERGY 650.8 joules
480 ftlbs

Shear Index 0.472

Impact Velocity = 5.47 m/s
17.9 ft/sec

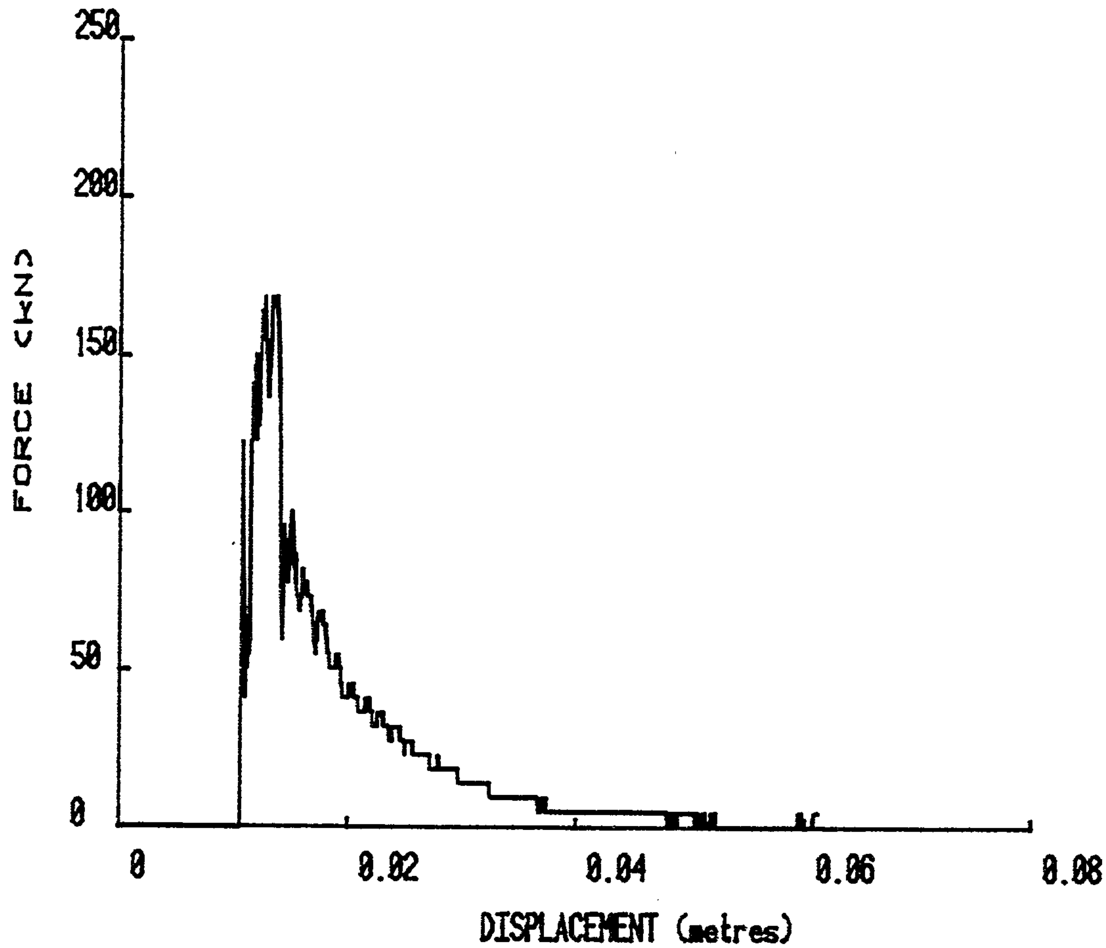


LOAD/LPD PLOT FOR: LASER1 HY800WM -30C15/6/3

DYNAMIC TEAR ENERGY 1256.4 joules
927 ftlbs

Shear Index 0.396

Impact Velocity = 5.47 m/s
17.9 ft/sec

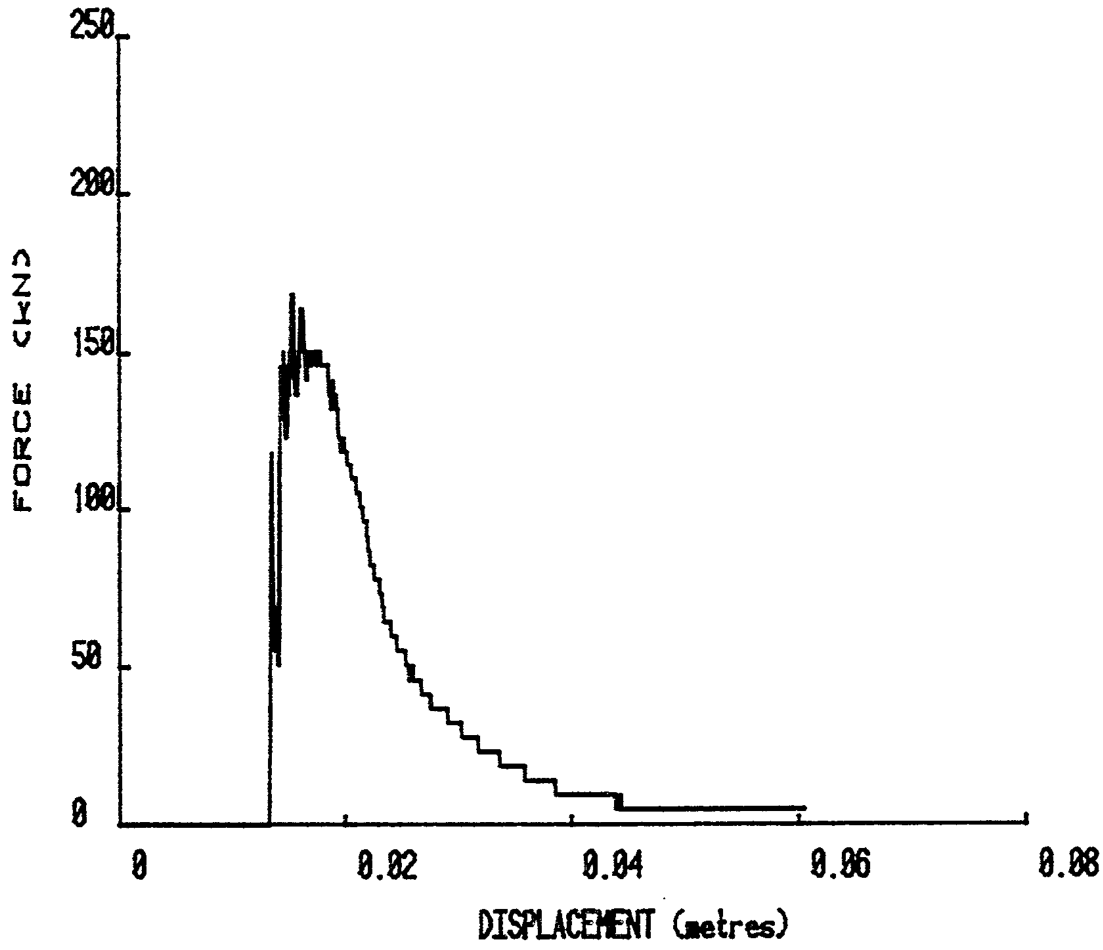


LOAD/LPD PLOT FOR: LASER2 HY80 HAZ -30C 15/6/4

DYNAMIC TEAR ENERGY 1800.4 joules
1329 ftlbs

Shear Index 0.432

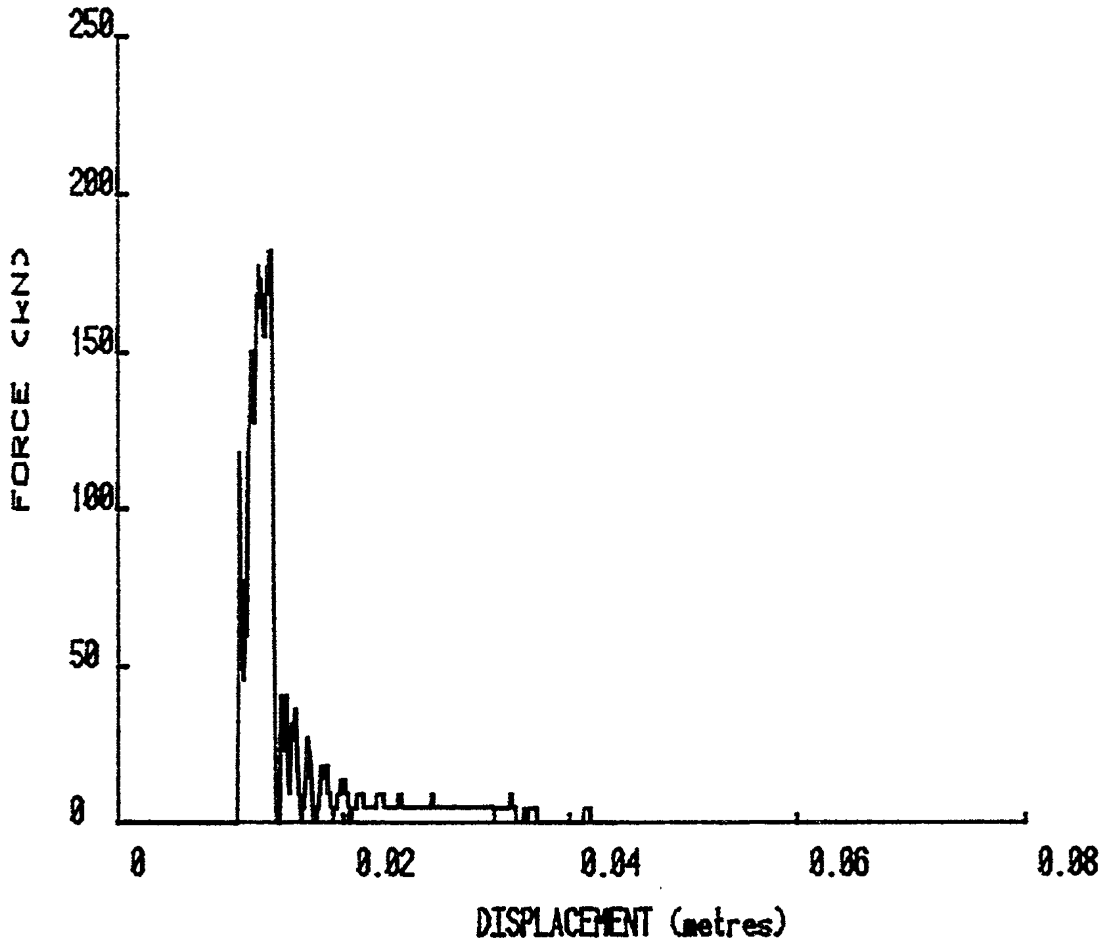
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: LASER3 HY80 WM -45C 15/6/8

DYNAMIC TEAR ENERGY	660.1 joules
	487 ftlbs
Shear Index	0.198

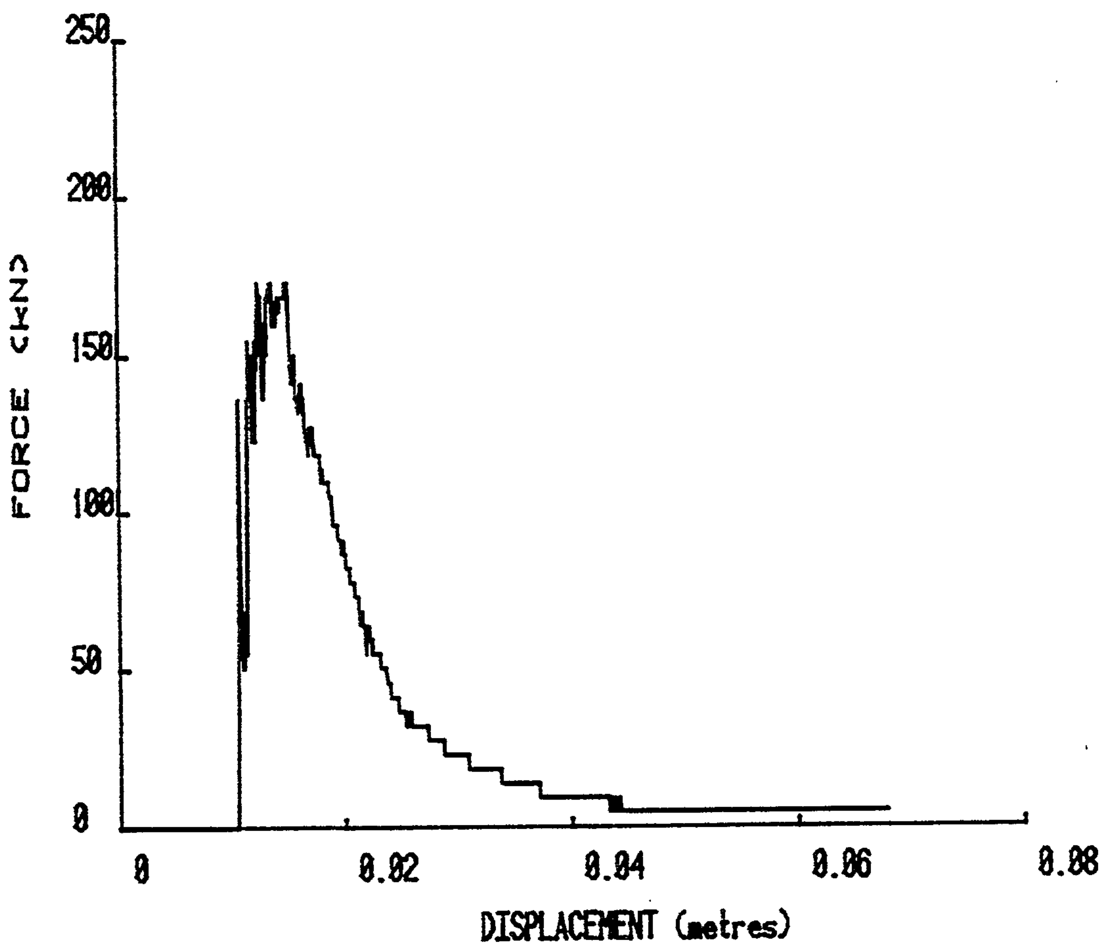
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: LASER4 HY80 HAZ -45C 15/7/2

DYNAMIC TEAR ENERGY	1998.6 joules 1474 ftlbs
Shear Index	0.439

Impact Velocity = 5.47 m/s
17.9 ft/sec

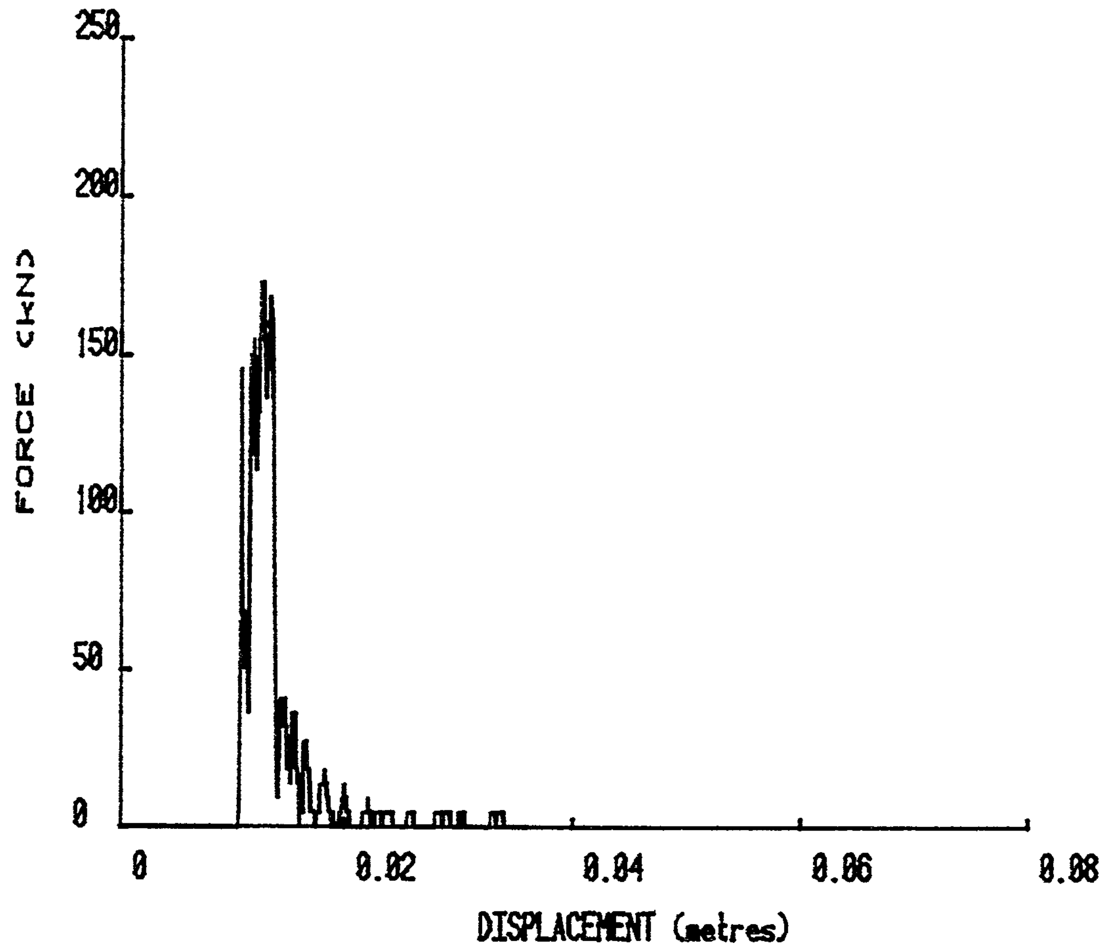


LOAD/LPD PLOT FOR: LASER5 HY80 WM -15C 15/7/6

DYNAMIC TEAR ENERGY 511.8 joules
378 ftlbs

Shear Index 0.224

Impact Velocity = 5.47 m/s
17.9 ft/sec

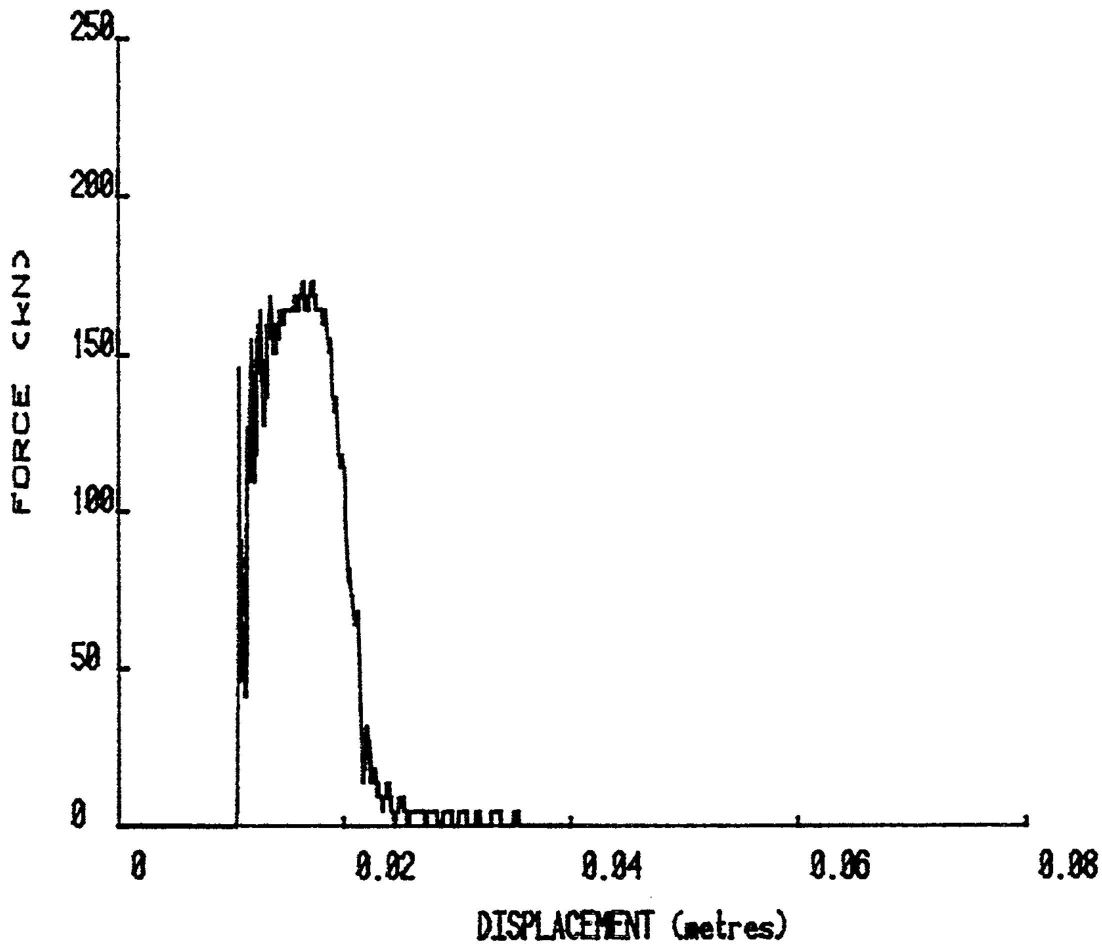


LOAD/LPD PLOT FOR: LASER6 HY80 HAZ -15C 15/7/8

DYNAMIC TEAR ENERGY 1547.3 joules
1142 ftlbs

Shear Index 0.364

Impact Velocity = 5.47 m/s
17.9 ft/sec

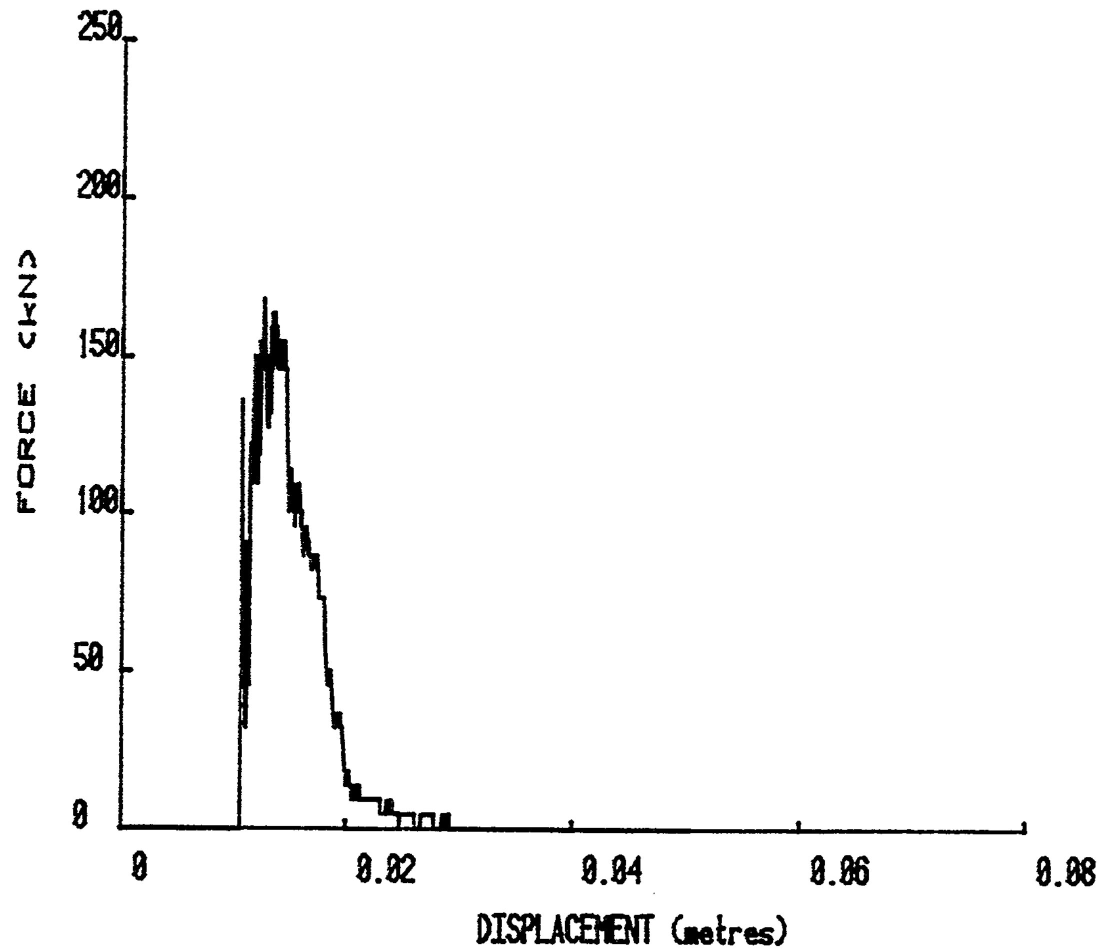


LOAD/LPD PLOT FOR: LASER7 HY80 WM 0C 15/8/3

DYNAMIC TEAR ENERGY 962.7 joules
711 ftlbs

Shear Index 0.374

Impact Velocity = 5.47 m/s
17.9 ft/sec

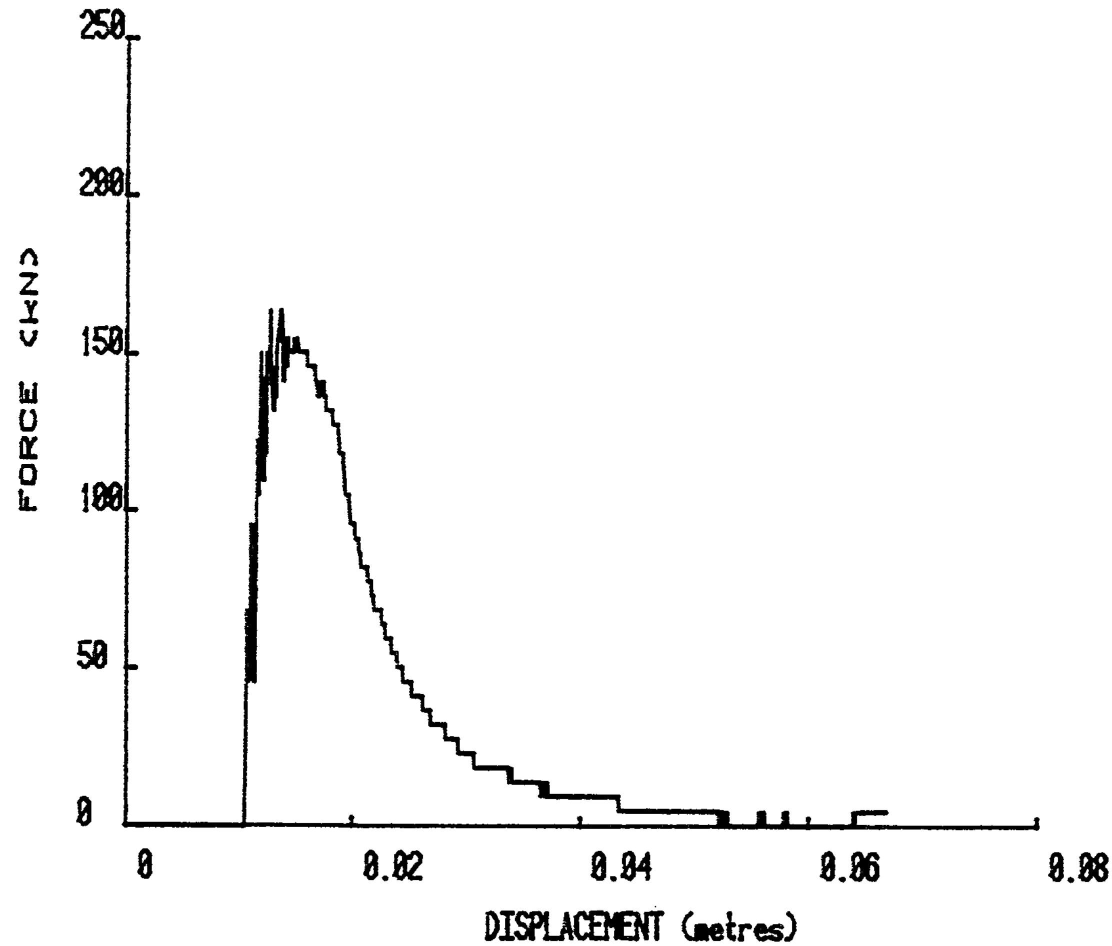


LOAD/LPD PLOT FOR: LASER8 HY80 HAZ 0C 15/8/4

DYNAMIC TEAR ENERGY 1956 joules
1443 ftlbs

Shear Index 0.478

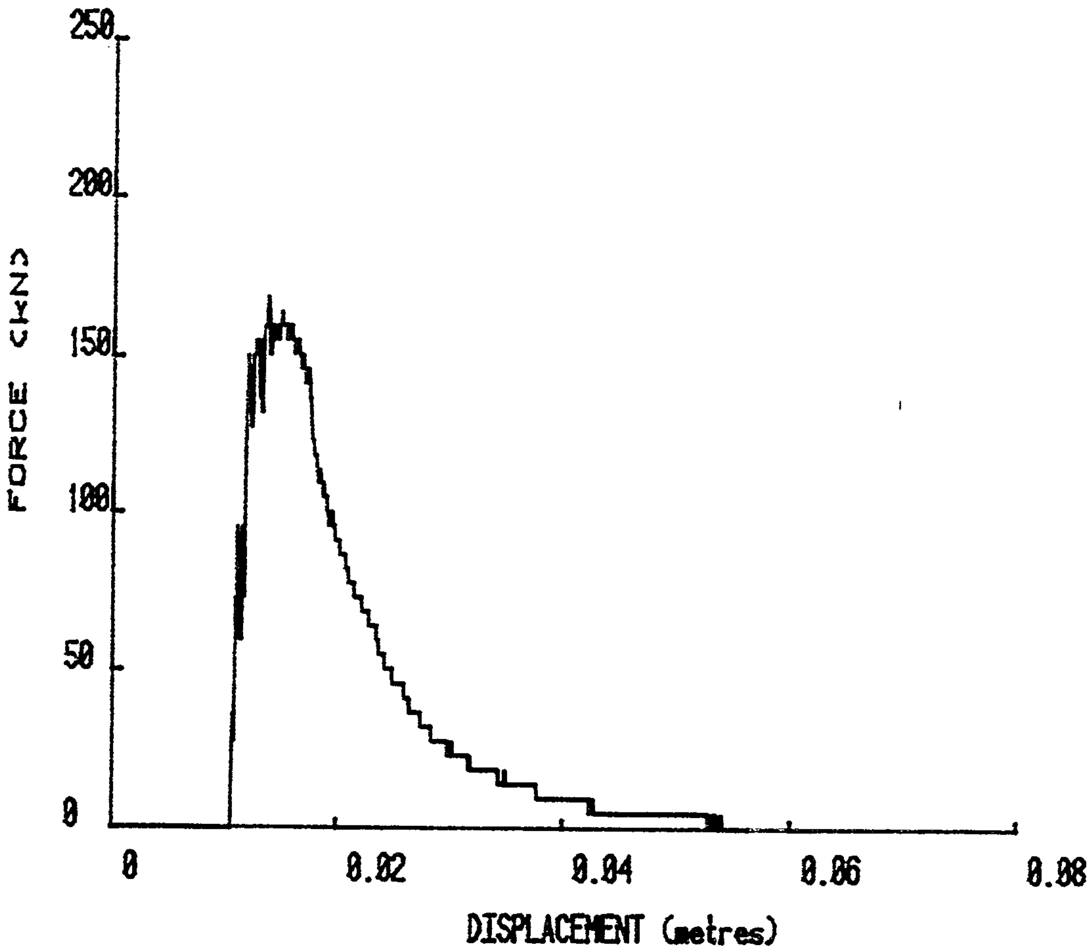
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: LASER9 HY80 WM 15C 16/1/1

DYNAMIC TEAR ENERGY	1958.3 joules 1444 ftlbs
Shear Index	0.441

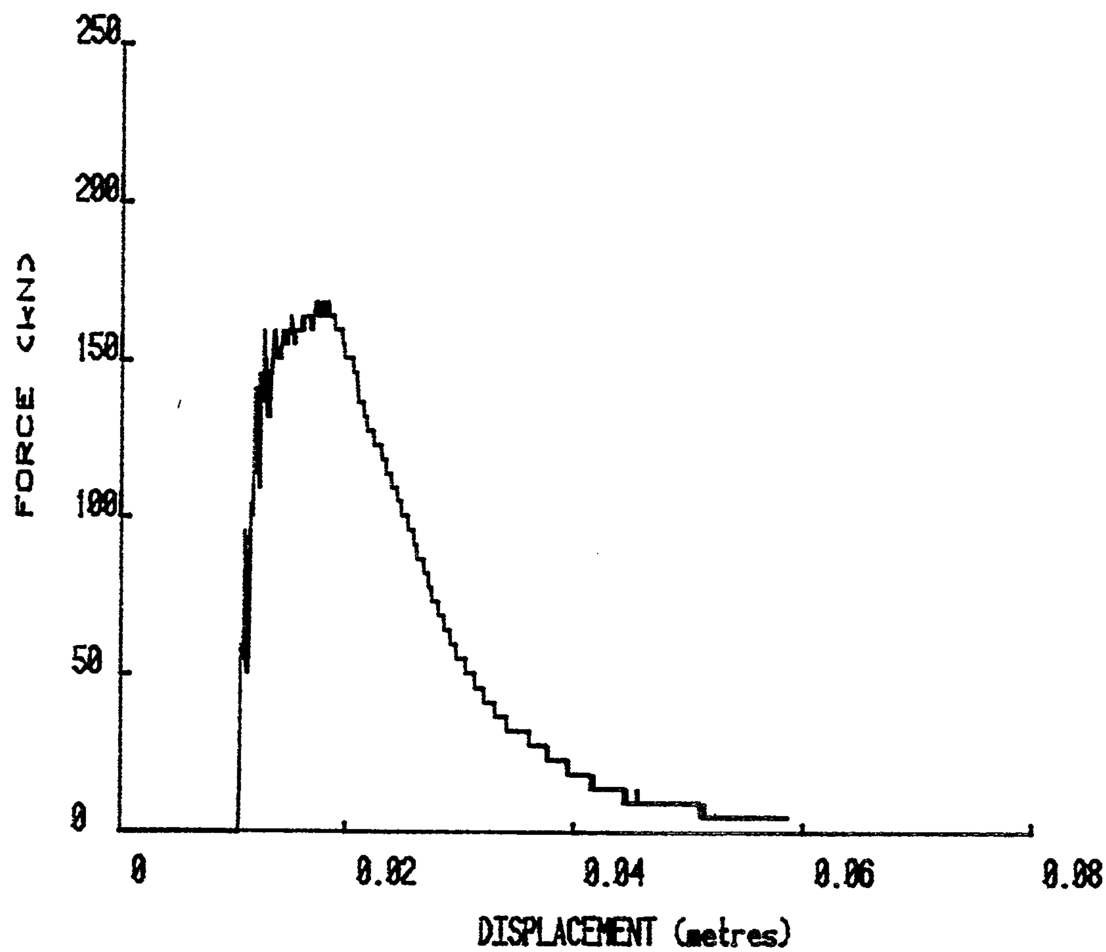
Impact Velocity = 5.47 m/s
17.9 ft/sec



LOAD/LPD PLOT FOR: LASER10 HY80 HAZ 15C 16/1/2

DYNAMIC TEAR ENERGY	2883.1 joules 2127 ftlbs
Shear Index	0.509

Impact Velocity = 5.47 m/s
17.9 ft/sec



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K. MacKay and M.W. Chernuka

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Dynamic tear specimens of welds from two previous DREA investigations were tested. The 25 mm thick specimens included two gas metal arc welds (Fronius-Time) each made in HY80 and HY100 steels. A weld produced by laser assisted gas metal arc welding (LAGMAW) in HY80 steel was also tested with specimens notched in the weld and in the heat affected zone (HAZ).

The Fronius-TIME 3G weld outperformed the HY80 Fronius-TIME 1G/4G weld in the dynamic tear tests with the LAGMAW weld giving the poorest performance of the HY80 welds tested. For the HY100 the Fronius-TIME 1G/4G weld gave highest dynamic tear energies for each temperature which is possibly due to the fracture path including a combination of HAZ, weld metal, and parent metal. All welds tested met the requirement of 690 J at -29 C except for the LAGMAW weld which gave a dynamic tear energy of 512 J at -15 C.

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